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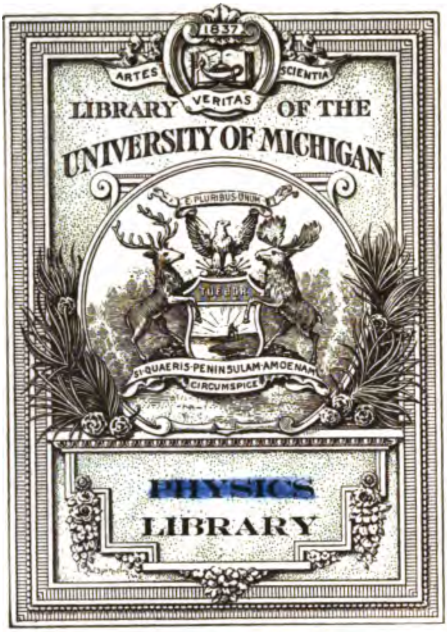

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NEIL ARNOTT, M. D. F. R. S.

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OR

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1887.

ELEMENTS OF PHYSICS

OR

NATURAL PHILOSOPHY.

BY NEIL ARNOTT, M.D., LL.D., F.R.S.,
MEMBER OF THE ROYAL COLLEGE OF PHYSICIANS, PHYSICIAN EXTRAORDINARY TO THE QUEEN, AND MEMBER OF THE SENATE OF THE UNIVERSITY OF LONDON.

SEVENTH EDITION,

EDITED BY

ALEXANDER BAIN, LL.D.,
PROFESSOR OF LOGIC IN THE UNIVERSITY OF ABERDEEN;

AND

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1887.

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PREFATORY NOTICE

TO THE

SEVENTH EDITION.

NEIL ARNOTT, the author of 'Elements of Physics,' was born on the 15th May, 1788, at Arbroath in Scotland, and died in London on the 2nd March, 1874. His father was of a Lowland family of good standing, and his mother was the daughter of Maclean of Borreray, a Highland clan. He married late in life and left no child to inherit his name.

Dr. Arnott's early days were passed at Dysart, not far from Montrose. He entered the Aberdeen Grammar School in November, 1798, and remained there three years. He went into the Bursary competition at Marischal College in 1801, and having been successful, he was entered as a student at this college, where he went through the usual curriculum. During the third year, he took up the study of Natural Philosophy under Professor Copland, who appears to have been an admirable teacher and a man well calculated to fix the attention and impress the minds of students. It was while attending Copland's lectures, that the mind of the young pupil was first strongly directed to NATURAL PHILOSOPHY. He obtained his M.A. degree in 1805, when he was in his seventeenth year.

For the purpose of perfecting himself in the medical profession, Dr. Arnott went to London, in 1806, and he became a pupil under Sir Everard Home at St. George's Hospital. Through the influence of Sir Everard, he obtained an appointment as surgeon in the East India Company's medical service. Much of the experience which he thereby obtained during his life at sea, he afterwards turned to a good account in preparing his 'Elements of Physics.' Dr. Arnott settled in London in 1811, and he soon obtained a large practice. In 1815 he was appointed physician to the French Embassy, and subsequently to the Spanish Embassy.

In 1813, he gave, at the Burton Rooms, a course of lectures on Natural Philosophy applied to Medicine, and in 1825, he gave two courses on the same subject at his house in Bedford Square. He declined to repeat these lectures, and in 1827 he first published the substance of them in the 'Elements of Physics,' the work by which he has become so well known in the scientific world. In 1838 he brought out an 'Essay on Warming and Ventilation,' and carrying his scientific theories into practice, he invented the "stoves" which bear his name, for which invention he was rewarded by the Royal Society with the Rumford Medal. For this and for other novel applications of science to the treatment of disease and the preservation of public health, the jurors of the Universal Exposition of Paris of 1855, awarded to him a gold medal, to which the Emperor Napoleon III. added the Cross of the Legion of Honour. On the foundation of the University of London, in 1836, Dr. Arnott was appointed an original member of the Senate. In 1837 he was named one of the Physicians Extraordinary to Her Majesty; and in the following year, elected a Fellow of the Royal Society. In 1854 he was requested by the President of the General Board of Health to become one of his Medical Council, and at this period, he devoted a large portion of his time to education and public works. As the inventor of the "Arnott stove" the "Arnott ventilator," and the Water-bed, for which many a sufferer owes him a debt of gratitude, it is not likely that his name will soon be forgotten; but it deserves to be recorded in his honour that he refused to patent his inventions. His great object, as well as his guiding principle through life, was to benefit others and not to obtain pecuniary profit.

One great secret of Dr. Arnott's success was that, from his earliest days, he was an acute observer of all that went on around him. Nothing bearing upon Physics escaped his notice. He stored these observations in his mind for future use, and made memoranda of all natural phenomena as they occurred. In addition to an active mind, by which every event bearing upon Natural Philosophy was thus appropriated, he possessed happy powers of description. The reader was not only instructed, but made to feel a strong interest in the subject. He had not to wade through pages of dry technical essays on physical facts and theories in order to add to his store of knowledge. He found it here provided for him in a form which rendered instruction a pleasing recreation. If this were a biography of Dr. Arnott, much might be recorded that would interest his friends and demonstrate the various powers of his mind. He had a fair knowledge of the classics and was familiar with the chief foreign languages. He had a decided talent for music and also for drawing.

Dr. Neil Arnott has not only contributed to advance physical science by precept, but he has set a good example to others by endowing scholarships for the purpose of encouraging the study of Natural Philosophy in Universities and public schools. We may here mention the following:—In 1869, £2000 granted to the University of London, and £1000 to each of the following Universities: Aberdeen, Edinburgh, Glasgow, and St. Andrews. In a communication to Dr. Lyon Playfair, he announced his intention of making an additional contribution of £1000 to each of the four Scotch universities. As he did not carry out this intention either in his lifetime or by bequest, his widow has, since his death, made a further contribution of £1000 to each of these Universities, in order that her husband's wishes to promote the study of Natural Philosophy, might be completely and effectually fulfilled.

Notwithstanding the many good popular treatises on Natural Philosophy that have been published of late years, the peculiar excellence of the 'Elements of Physics,' as regards style and illustration, is as yet unsurpassed, if it has been equalled. This seems amply to justify the republication of the work, even although the progress of discovery has rendered necessary, many additions and alterations which could no longer be made by the author's own hands.

The editors of this edition, being Dr. Arnott's literary executors, were charged by him to adapt the work to the present state of knowledge, while retaining in his own words, all that was permanent in the doctrines and exposition of the subject. In performing this task, they have endeavoured, so far as the language and selection of the topics are concerned, to preserve the popular character of the work. Besides using the author's notes, they have referred to the best modern authorities in making the requisite additions.

In the revision and adaptation of the work, the editors have received and profited by the assistance of a gentleman who has devoted his time to the study of physical science, and who has made its recent advances a subject of special research.*

Throughout his life, and by his various inventions and publications, Dr. Neil Arnott manifested a purely philanthropic desire to extend to others, the benefits of that knowledge which, from his boyhood upwards, he had acquired by long and patient observation. His earnest wish was to make the path of learning easy to all. We have now before us a copy of the 'Elements of Physics or Natural Philosophy' as it first appeared in 1827. Within five years of its publication, five large editions of the work were called for, and, although not then complete, it was translated into several foreign languages. It is not too much to say of this and his other works, that the learned and the unlearned, the student and the philosopher, have equally benefited by his labours.

---

* Mr. John Cook, M.A., Mathematical and Science Master, High School, Arbroath, and formerly Assistant-Professor of Natural Philosophy in the University of Aberdeen.

TABLE OF CONTENTS.

PART I.

SECTION I.—CONSTITUTION OF THE MATERIAL UNIVERSE.

PAGE		ART
1.	Analysis of the section.	
	Minuteness of matter: illustrations	1
4.	Matter imperishable	4
5.	Atoms: molecules: chemical elements	7
6.	Matter extended or impenetrable	11
7.	All matter gravitates: weight is the resisted attraction of the earth: gravity	13
8.	Law of gravitation—inversely as square of distance	18
10.	Other forms of attraction	22
11.	Cohesion: illustrations: restoration of cohesion	23
12.	Force of cohesion varies with distance	28
13.	Three states of matter, solid, liquid, gas, determined by cohesion and heat-motion	29
13.	Varieties of cohesive manifestation	30
14.	Porosity: illustrations: petrifaction	31
15.	Density: specific gravity	36
16.	Crystallization, a result of a molecular polar cohesion	40
18.	The amorphous state of bodies	46
19.	Hardness: Mohr's scale: tempering	48
20.	Brittleness: Rupert's drops: annealing	52
21.	Elasticity: elastic limit	54
22.	Pliancy: asbestos	58
23.	Malleability: metallic leaf	59
24.	Ductility: platinum wire	62
25.	Tenacity: resistance of materials to stretching: table	64
26.	Cohesion in liquids: limpid and viscous liquids	68
27.	Porosity, density, and elasticity of liquids	71
28.	Adhesion: examples	76
29.	Cements: adhesion in solids and liquids	78
31.	Solution due to adhesion	81
32.	Adhesion between liquids	82
33.	Capillary attraction: rise of liquids in fine tubes	84
34.	Capillary depression	88
35.	Interatomic or chemical attraction	91
36.	Chemical union destroys individuality of atoms	92

PAGE		ART.
37.	Chemical changes in the properties of bodies	93
38.	Chemical attraction does not interfere with gravitation	94
39.	Laws of chemical combination: results of chemical attraction	95

SECTION II.—PHENOMENA OR MOTIONS OF THE UNIVERSE.

PAGE		ART.
41.	Analysis of the section.	
42.	Motion and force defined	101
,,	Motion: velocity: table of velocities	102
45.	Uniform motion or velocity	105
46.	Variable motion	106
47.	Uniformly accelerated or retarded motion	107
,,	Absolute and relative motion	110
48.	Coexistence of motions	111
49.	Composition of motions: resultant	113
50.	Parallelogram of motions or velocities	116
51.	Resolution of motion: components	118
52.	Parabolic path of projectiles: illustrations	120
53.	Force, a compound of matter and motion	122
,,	Actual and potential force	124
54.	Different forms of force: gravitation, cohesion, chemical attraction, heat, magnetism, electricity, light	125
55.	Momentum: measure of force: examples	126
57.	Composition and Resolution of force	129
58.	Uniform and Variable forces: their measure	131
59.	Accelerated force: examples	132
,,	Gravity a uniformly accelerated force	133
62.	Fall of bodies in vacuo	135
63.	Attwood's machine	136
65.	Laws of falling bodies	139
,,	Measure of gravity	141
67.	Retarded force: illustrations	145
69.	Newton's Laws of Motion: First Law	147
70.	Inertia: examples	149
73.	Free motion is uniform: perpetual motion impossible	153
74.	Popular idea of inertia: celestial motions	154
75.	All natural motions retarded	156
77.	Free motion is straight: examples	159
78.	Centrifugal force: examples: the whirling table	158
81.	Laws of centrifugal force: examples: the centrifugal railway, Saturn's-ring experiment	161
82.	Newton's Second Law of Motion	165
84.	Newton's Third Law of Motion: action and reaction—illustrations	167
86.	Concussion of elastic bodies	170
,,	Interference of pendulum vibrations and of vibrating magnets	171
88.	The principle of Energy	172
89.	Energy: measure of work: work-power	174
90.	Unit of work: Foot-pound: Kilogrammetre	176
91.	Relations of Energy to Velocity	179
93.	Different Forms of Energy	182

PAGE ART.
95. Kinetic and Potential condition of all Energy... 183
96. Illustrated by the pendulum 184
,, Cohesion—Kinetic and Potential: watch-spring 185
97. Chemical, kinetic, and potential Energy 186
98. Kinetic and potential heat-energy 188
99. Correlation of Energies or Forces 190
101. Mechanical Equivalent of Heat... 192
102. Conservation of Energy 193

PART II.

SECTION I.—THE CENTRE OF GRAVITY.

103. Analysis of the section.
,, Centre of gravity defined 194
104. Practical method of finding the Centre of Gravity 196
105. Centre of Gravity of homogeneous mass 197
,, Of any two connected masses 198
,, Of a triangular plate or rods 199
106. Of a pyramid and of a cone 200
107. Centre of gravity tends downwards 202
108. Illustrations of this tendency 203
109. Stability of position and structure 205
110. Examples of stable and unstable equilibrium 207
112. Attitudes of animals illustrate this 210
114. Sea-sickness 213
115. Vegetable forms illustrate this subject 214
116. Centre of action or force: centre of centrifugal force ... 217
117. Centre of percussion: of oscillation 219

SECTION II.—THE SIMPLE MACHINES.

119. Analysis of the section.
,, The mechanical Powers 221
120. Real object of simple machines 223
122. The lever: does not magnify force 226
,, Perpetual motion impossible 227
123. The lever: its real use examined 228
124. Lever of first kind: illustrations 231
125. Common balance: steelyard 233
127. Lever of second kind: examples 236
128. Lever of third kind: compound and bent levers 237
129. Wheel and axle: capstan: windlass, &c. 240
131. Toothed-wheels: cranes: spinning-wheel 243
133. The inclined plane: railway gradients 244
134. The wedge: examples 246
135. The screw: its applications 248
136. The pulley: fixed and movable pullies 250
138. Extension of the term "Mechanical Power" 253

PAGE ART.
139. Classes of machines:—
,, (i.) Mere modifiers of velocity: the knee-joint, the lazy-tongs 254
140. (ii.) Cumulative machines: fly-wheels 257
141. (iii.) Modification of direction 258
142. Straight changed into rotary: and rotary into straight ... 259
143. The crank: the eccentric 261
144. Parallel motions: simple: Watt's: Peaucellier's 263
145. Modification of motion as to direction: cause 265
146. Time: pendulum motion 266
147. Its isochronism: the seconds pendulum: the metronome ... 267
149. Friction: Angles of Repose 268
151. Laws of friction: examples: antifriction expedients 271
153 Wheeled-carriages: use of springs 275
155. Strength of structures and materials 278
,, Large structures proportionally weak 279
156. Size of hills, of animals, of vegetables, of roofs, arches, &c., limited by this principle 281
158. Strength of columns: examples 285
160. Strength of beams: girders: tubular bridges 288
162. The strength of the arched form illustrated 291

PART III.

SECTION I.—HYDROSTATICS OR THE LAWS OF LIQUID PRESSURE.

165. Analysis of the section.
166. Fluid: liquid: gas 293
,, Fundamental property of fluids 294
167. The hydrostatic paradox 297
168. Examples of liquid pressure: the hydrostatic bellows: the Bramah Press 298
170. Liquid pressure varies with depth: illustrations 301
173. Liquids press in all directions 304
174. Horizontal surface of liquids at rest 306
175. Liquids seek their own level 308
176. Illustrations of this law 309
177. Levelling: the spirit-level 310
179. Canals: the Suez canal 311
180. Geological effects of liquids seeking their level 312
181. Deltas and plains formed by rivers: the Nile, Rhone, Rhine, Ganges, &c.: tides: inundations 314
184. Water-springs: Artesian wells 315
186. Liquids of different densities 316
,, Archimedes' principle: liquid buoyancy: the conditions of floating 317
188. Loss of weight in water 320
190 Floating: hydrostatic paradox 322

PAGE. ART.
191. Stability of floating: centre of buoyancy ... 324
192. Swimming: life-preservers: Boyton's life-saving dress ... 325
195. Increase of buoyancy with density of liquid ... 328
196. Liquids floating on liquids ... 329
197. The heat-transferrer ... 331
198. Finding specific gravity of solids ... 333
201. Specific gravity phial: specific gravity of liquids and gases: of soluble solids: of powders ... 335
203. Hydrometers: Nicholson's hydrometer ... 341
204. Specific gravity of spirits, milk, &c. ... 343
205. Table of specific gravities ... 345

SECTION II.—HYDRAULICS OR THE LAWS OF LIQUIDS IN MOTION.

207. Analysis of the section.

,, History of the science ... 346
208. Law of liquids issuing by an orifice ... 347
209. The vena contracta ... 349
210. Frictional resistance to moving fluids ... 350
,, The flow of liquids through orifices ... 352
211. Liquid friction ... 355
212. Waves—their velocity: height: form: the bore of a river ... 357
214. Liquid inertia: law of liquid resistance ... 360
216. Applications to navigation ... 362
217. Aërial resistance ... 364
,, Limit to velocity through air and other fluids... 365
218. Fluid resistance influenced by shape of solid ... 367
220. Water-wheels: undershot, breast, and overshot ... 369
,, Atmospheric resistance: the water-hammer ... 370
222. Power of moving fluids: levigating: geological action of liquids: winnowing ... 373
223. Oblique fluid action—of wind on a sailing vessel ... 375
225. Oblique action of ship's helm: gun rifling ... 377
226. Windmill: feathering of an arrow ... 381
228. The screw-propeller—its power due to oblique action ... 383
230. Hydraulic machines: bucket-wheel: chain-pump: rope-pump 387
231. The Archimedean screw: Persian wheel ... 389
232. Hydraulic ram: Barker's mill: Turbine: Centrifugal-pump 391

SECTION III.—PNEUMATICS.

235. Analysis of the section.

,, History of the science ... 395
237. Air—its lightness and elasticity ... 398
238. Valves: condensing syringe: the air-pump ... 400
239. Law of gaseous elasticity ... 403
240 Aërial elasticity illustrated: air-gun ... 404
242. Air-fountain: the fire-engine: diving-bell ... 406
244. The Cartesian diver ... 409
245. Hero's fountain ... 410
246. Pressure of fluids in all directions ... 411
247. Kinetic theory of gases ... 412

PAGE ART.
248 The Law of Charles ... 413
,, The weight of the atmosphere ... 414
249. Illustrations of aërial pressure: the Magdeburg hemispheres 415
252. Atmospheric pressure: Torricelli's experiment ... 418
254. The sucking or lifting pump ... 419
255. The force-pump: the syphon ... 420
256. Examples of the syphon principle ... 422
257. Atmospheric pressure illustrated ... 423
259. The air-bladder of fishes: cupping ... 424
261. Physiological effects of air-pressure ... 426
,, The Barometer ... 427
263. Different forms of the barometer (standard, syphon, and wheel) 428
265. The aneroid: Bourdon's barometer ... 429
266. The barometer as a weather-glass: rains and storms ... 430
268. Barometric observations: the barometric gradient ... 432
269. Meteorological maps: cyclonic motions of storms ... 433
270. Measurement of mountains by the barometer ... 434
272. Limits of the atmosphere: fall of the barometer as we ascend 435
274. Air-pump gauge ... 436
275. Use of barometer to find specific gravity ... 437
,, Use of barometer in mines ... 438
276. Effects of atmospheric pressure ... 439
277. Buoyancy of air: balloons ... 441
279. The fire-balloon: modern ascents: the Paris siege-balloons 443
282. The principles of ventilation: flame and smoke ... 445
,, Draughts: fire-places and stoves: causes of smoky chimneys 447
286. Winds: the trade-winds: the sea-breeze and land-breeze of the tropics ... 449
288. Monsoons: cyclones: typhoons ... 451
291. The pneumatic trough and gasometer ... 454
292. Diffusion: laws of liquid diffusion ... 456
294. Diffusion of gases: its laws ... 458
296. Osmose: osmometer: endosmose: exosmose ... 460
297. Crystalloïd and colloid bodies: dialysis—its medical uses ... 462
299. Osmose of gases: experiments: operation of osmose... ... 464
,, Perfect vacua: Geissler's and Sprengel's air-pump ... 468

SECTION IV.—ACOUSTICS OR THE PHENOMENA OF SOUND AND HEARING.

305. Analysis of the section.
,, Sound is motion ... 471
307. Sonorous media: influence of form on vibration of a solid ... 473
308. Sound-waves: wave-motion: chain-waves: amplitude ... 475
311. Aërial rarefactions and condensations: power of air to transmit mechanical shocks: explosions ... 477
312. Effects of vibrations on flames: sensitive flames ... 479
314. The Æolian harp: the vocal Memnon: sea-shells ... 482
315. Sounds conveyed by solids and liquids: sympathetic sounds 483
316. Velocity of sound in hydrogen and in air ... 484
317. Conductibility of solids ... 485

PAGE		ART.
318.	The stethoscope	487
319.	Velocity of sound in air: its measure: its variation with temperature, &c.	488
322.	Velocity of sound in liquids and solids	492
324.	Intensity of sound	494
,,	Echoes: reflection of sound	495
326.	Acoustic transparency of the air	497
327.	Acoustic reversibility: Tyndall's experiments	498
330.	Musical note from an echo	499
,,	Concentration of sound: whispering galleries	500
333.	The ear-trumpet: the speaking-trumpet: acoustic deceptions	503
336.	Musical sounds and noises	508
337.	Means of producing musical sounds	510
339.	The three elements of a musical sound	512
340.	Pitch of a tone: its cause: the syren, its construction and use	513
342.	The musical scale: octaves	515
343.	Numerical relations between the notes of the scale	517
345.	Length of musical air-waves	519
,,	Quality, colour, or timbre of a note: its physical explanation	520
346.	Recording sonorous vibrations: the phonautograph	522
347.	Harmonics: Helmholtz's view: overtones	524
349.	Resonance: Helmholtz's resonators	527
351.	Sounding-strings: harmonics of a string: Æolian harp	529
353.	Laws of vibrating strings: ventral segments	532
355.	Musical chord: key-note: melody, harmony, time	535
357.	Sounding plates and rods: the tuning-fork	539
359.	Chladni's sound-figures	542
360.	Vibrations of rods and wires	543
361.	Kundt's experiments	544
363.	Sounding air-columns: organ-pipes: their mode of vibration: reed-pipes: the voice: the glottis	546
365.	Singing-flames: the chemical harmonicon	551
366.	Musical glasses	552
367.	The animal ear: perception, duration, direction, intensity of sounds: ventriloquism	553

PART IV.

IMPONDERABLES.

373.	Heat, Light, Electricity, and Magnetism	554
374.	The material and dynamic theories	555

SECTION I.—HEAT.

377.	Analysis of the section.	
378.	Heat the supporter of Animal and Vegetable Life	559
379.	Influence on climate	560
,,	Heat and Temperature	561
381.	The Radiometer	563

PAGE ART.
383. Heat a form of Energy ... 564
384. Mechanical theory of Heat ... 565
385. The Sun the natural source of Heat ... 566
386. Amount and intensity of Solar radiation ... 567
387. Influence of Solar Heat on the Globe ... 569
,, Hybernation of animals ... 571
388. The source of Solar Heat ... 572
389. Terrestrial or Subterranean Heat ... 573
390. Artesian Wells and Thermal Springs ... 574
,, Volcanoes ... 575
391. Temperature of deep mines ... 576
392. Deep sea temperatures ... 577
394. Polar currents in the Atlantic ... 578
395. Source of terrestrial heat ... 579
,, Change of bulk caused by heat ... 580
396. Physical states of matter dependent on heat ... 581
397. Illustrations from mercury and camphor ... 582
398. Gases and vapours the result of heat ... 583
399. Liquefaction and solidification of gases ... 584
401. Diffusion of Heat: equalization of temperature ... 588
402. Heat and Cold relative terms ... 589
403. Conduction of Heat ... 590
404. Relative Conductivity of Solids ... 591
405. Conductors and Non-conductors ... 593
406. Bad conductors: clothing ... 595
408. Natural coverings of animals ... 597
409. Influence of Snow and Ice ... 598
410. Conducting power of the Earth ... 599
411. Frozen soil of Siberia ... 599
412. Retention of Heat by bodies ... 601
413. Action of Heat on Glass ... 602
414. Annealing and Tempering of solids ... 603
415. Estimation of sensible Heat ... 604
416. Influence of Clothing ... 606
417. Principles of the safety lamp ... 607
420. Convection of Heat ... 610
422. Warming by circulation of hot water ... 612
423. Oceanic currents: Gulf Stream ... 613
425. Climatic changes ... 614
426. Ventilation of dwellings ... 616
,, Heat transferred ... 617
428. Radiation of Heat ... 618
431. Radiation, Absorption, and Reflection of Heat ... 621
433. Reflection of Heat rays ... 624
435. Diaphanous and Diathermanous bodies ... 626
436. Formation of dew ... 628
439. Temperature of space ... 632
440. Capacity of bodies for heat ... 633
441. Specific heat ... 635
443. Line of perpetual snow ... 638
445. Humidity dependent on Temperature ... 641

PAGE ART.
447. Hygrometers 645
448. Wet bulb thermometer 648
450. Formation of Glaciers and Icebergs 652
453. Expansion of bodies by heat 658
455. Increase of bulk in solids 660
459. Expansion of liquids 664
460. Expansion of Gases 666
462. Unequal expansion 667
463. Latent Heat of bodies 669
469. Boiling point of water 675
470. Spheroidal state of liquids 676
473. Distillation 681
476. Superheated steam 683
479. Pressure of steam for different temperatures 687
481. Expansive force of steam 690
482. The steam gun 691
483. The modern Steam-engine 692
491. The Cryophorus 700
494. Condensation of vapours 704
497. Freezing mixtures 708
498. The thermometer... 711
501. The different Scales 713
504. Differential thermometer 716
505. Pyrometers 717
506. Table of high and low temperatures 718
507. Passage of Heat into Light 720
509. Chemical effects of Heat 721
511. Influence on germination and incubation 724
512. Phenomena of combustion 725
515. Combustion with and without oxygen 729
517. Spontaneous combustion 731
518. Ignition: incandescence... 734
519. Supporters of combustion and combustibles 735
521. Heat and light of combustion 736
523. Nature of flame 738
525. Products of Combustion... 742
529. Fuel 749
536. Temperature of the bodies of animals 758
537. Heat borne by man and animals 760
539. Influence of heat on animals 763
540. Source of animal heat 764
542. Artificial Climate: Warming of dwellings 767
546. Stoves and fire-grates 770
548. Mechanical equivalent of heat 773
553. Heat from Collision of bodies 778

SECTION II.—LIGHT.

555. Analysis of the section.
556. Sources of Light 779
557. Light from the Sun 781

PAGE ART.
558. Light from Combustion 782
559. Drummond and Bude lights 784
560. Phosphorescence: Light from Animals 786
562. Separation of Light and Heat 789
563. Calorescence 789
565. Non-luminous bodies 792
567. Light proceeds in straight lines 795
569. Photometry and Photometers 799
571. Velocity of light 801
573. Transparent and opaque substances 803
574. Refraction of light 804
578. Atmospheric refraction 808
579. Mirage: Fata Morgana 810
582. Decomposition by refraction 812
585. Action of Lenses 814
592. Optical Instruments 822
594. The structure of the Eye 824
596. Phenomena of Vision 825
601. Persistence of Impressions 830
604. Complementary colours 834
606. Rules of Perspective 836
612. Apparent size of objects 842
617. The Vanishing point 848
629. Light and Shade: Chiaroscuro 861
636. Principles of the Stereoscope 868
642. The Telescope 872
647. The Microscope 878
649. Reflection of Light 880
656. Concave and Convex mirrors 889
659. The Camera Lucida 892
660. The Rainbow 893
663. Solar Spectrum and Spectrum analysis 896
665. Fluorescence 899
667. The Spectroscope 902
672. Constitution of the Sun and Stars 907
673. Chemical properties of Light 908
676. Emission and Wave theories 910
678. Phenomena of Interference 914
683. Polarization of Light 920
688. Polarization of Heat 925
689. Old and New Theories of Light 927

SECTION III.—ELECTRICITY.

692. Nature of Electricity 928
694. Illustrations of its production 930
696. Conductors and Insulators 933
697. Electrical Machines 934
700. Electrical Induction 939
702. The Electroscope 940
704. The Electrophorus 942

PAGE ART.
706. Holtz's Induction Machine 944
707. The Leyden Jar 945
709. The Electric Battery 947
712. Velocity of the Electric flash 951
713. The Electricity of the Atmosphere 952
715. Current or Voltaic Electricity 954
719. Voltaic batteries 958
721. Daniell's battery and its varieties 959
722. Grove's and Bunsen's Batteries 960
724. Manipulation of Batteries 963
726. Galvanic deposition of metals 964
727. Electrolysis 965
728. Decomposition of Water... 966

SECTION IV.—**MAGNETISM.**

731. Magnetic attraction: the Loadstone 967
732. Magnetism a polar force... 968
734. Magnetic Induction 970
,, Magnetization of iron 971
736. The Electro-magnet 973
737. Diamagnetism 974
738. Terrestrial Magnetism 975
739. Variations of the Compass 976
740. Magnetic charts 977
741. Electro-magnetism 979
743. Galvanometers 981
745. Electro-dynamics 983
746. Electro-magnetic Engines 984
747. Electric clocks 985
748. Induced Electric currents 987
749. Ruhmkorff's Induction coil 988
752. Magneto-electric induction 991
756. Thermo-electricity 995
757. The Thermopile 997
758. The Electric Telegraph 998
763. The Morse Telegraph 1003
766. Submarine Telegraphs 1005
768. Duplex Telegraphy 1007
769. Rapidity of transmission 1009
770. Solar Telegraphy 1010

PART V.

ASTRONOMY.

773. Definition and Divisions of Astronomy 1011
774. The roundness and size of the earth 1012
779. The roundness caused by gravitation 1017

PAGE ART.
781. The Moon: its distance: measurement of celestial distances ... 1019
787. The Earth's rotation ... 1023
788. The apparent motion of the stars ... 1024
789. Illustration by a globe ... 1025
790. Uses of the Celestial Globe ... 1026
791. Apparent motion of the stars due to the Earth's motion ... 1027
792. The earth's motion proved by Foucault's experiment... ... 1028
,, Explanation of terms ... 1029
793. Instruments of the Astronomical Observatory... ... 1030
794. Mechanical view of the Earth's rotation ... 1031
796. The Earth's annual revolution about the Sun 1032
,, Proofs that the Earth moves round the Sun 1033
798. The Laws of Kepler ... 1034
799. Mechanical View of the Earth's revolution ... 1035
802. Inclination of the Earth's Axis of rotation, causing the Changes of the Seasons ... 1038
803. The Moon's revolution about the Earth ... 1039
805. Eclipses of the Sun and Moon 1040
806. The Surface of the Moon ... 1041
808. The Moon's revolution explained on mechanical principles ... 1042
,, The Lunar Theory: Perturbations of the Moon ... 1043
810. The Tides 1044
812. Precession of the Equinoxes ... 1045
,, Explained by Gravitation ... 1046
813. Nutation of the Earth's Axis ... 1047
814. Bodies composing the Solar System ... 1048
,, Supposed origin of the Solar System 1049
816. Table of the Solar System: illustration of distances 1050
818. The description of the Sun ... 1051
819. Explanation of the appearances... ... 1052
820. Forces at work ... 1053
821. The Planets:—Mercury 1054
,, Venus ... 1055
822. The Earth as a planet: determination of its Form, Size, and Density... ... 1056
824. Sun's distance from the Earth: Transit of Venus ... 1057
825. Determination of the Sun's Distance by Parallactic inequality 1058
,, Mars ... 1059
826. The smaller planets: Asteroids... ... 1060
827. Jupiter—the giant planet ... 1061
,, Saturn—the ring planet ... 1062
828. Uranus ... 1063
,, Neptune ... 1064
829. Comets ... 1065
830. Constitution of Comets 1066
,, Meteors and Aërolites 1067
831. FIXED STARS:—Constellations... ... 1068
832. Distance of the Stars 1069
,, Variable Stars ... 1070
833. Proper motion of the Stars ... 1071
,, Nebulæ ... 1072

PART VI.

ANIMAL PHYSICS.

SECTION I.—ANIMAL MECHANICS

PAGE ... ART.
835. Mechanism of the skeleton ... 1073
836. Constituents of the body ... 1074
837. The form of the skull ... 1075
838. Construction of the teeth ... 1076
839. The spinal column ... 1077
840. The ribs and chest ... 1078
841. Construction of the arm bones ... 1079
843. The bones of the leg ... 1081
845. Formation of the foot ... 1084
846. Muscular force ... 1085
848. Constituents of bone ... 1086
849. Structure and composition of the teeth ... 1087

SECTION II.—ANIMAL HYDRAULICS AND PNEUMATICS.

851. Circulation of the blood ... 1088
852. Plan of the circulation ... ,,
853. Constituents of the blood ... 1089
854. Products of the blood ... 1090
855. Chemical and vital processes ... 1091
856. Motion of the blood in the arteries ... 1092
857. The Capillary circulation ... 1093
858. Circulation through the veins ... 1094
859. Effects of gravitation on the blood ... 1095
860. The force of the heart ... 1096
861. The nature and cause of the pulse ... 1097
862. The sphygmograph ... 1097
863. Life dependent on the heart ... 1098
864. The number of pulsations ... 1100
865. Respiration or breathing ... 1102
867. Amount of air consumed ... 1104
868. Death from interrupted breathing ... 1105
869. Changes produced in the blood... ... 1106
871. Capacity of the lungs ... 1108
,, Aspiratory force in breathing ... 1109

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872 The Hydrostatic Bed ... 1110

PART I.

SECTION I.--THE CONSTITUTION OF THE MATERIAL UNIVERSE.

SUMMARY OR ANALYSIS OF THE SECTION.

MATTER, *or the extended universe, is built up of parts, so extremely minute as to be far beyond direct perception, but which receive the name* ATOMS, *because there is reason to believe that they have a permanent individuality of character corresponding to the inalienable differences of the simple or elementary bodies.*

A mutual ATTRACTION, *or drawing together, pervades all substance.*

It is seen most notably in the GRAVITATION, *which is exhibited by our earth, and the other orbs of space, and which dictates to them, according to a discovered law, their shape and course.*

An analogous, if not identical attraction—COHESION—*gives consistency to smaller masses, and its degrees, depending on the opposing effect of* HEAT-MOTION, *correspond to the most obvious division of substances, viz.,* SOLIDS, LIQUIDS, GASES. *Combined with ultimate specialities, it produces the physical qualities described by the names—"Porous," "Dense," "Crystalline," "Amorphous," "Hard," "Brittle," "Elastic," "Malleable," "Ductile," "Pliant," "Tenacious."*

Two allied attractions are also of much importance:—ADHESION, *as illustrated by cements, solutions, and alloys;* CAPILLARITY, *as explaining many phenomena of animal and vegetable life, and of common observation.*

Lastly, INTERATOMIC (CHEMICAL) ATTRACTION, *a most potent agency in the world around us, is more obscure in its action, infinitely diversified and altogether incalculable in its effects, previously to experience.*

"Matter built up of extremely minute parts."

1. The smallest portion of matter that the human eye can see is really a collection of many minute particles, called atoms or molecules, which may be separated, assorted,

or re-arranged, but which no natural power can in the least alter or destroy. In order that some idea may be formed of the minuteness of these ultimate grains, we shall give a few examples to show how far the division of matter may be carried within the region of the seen and tangible :—

A solid or liquid may by mechanical or chemical processes be reduced into particles so fine that they are no longer perceptible to the eye. When so reduced that a single particle is only the 500,000th of an inch in diameter, it would be no longer visible under a powerful microscope. A small quantity of mercury shaken in a bottle with strong oil of vitriol is temporarily split into myriads of minute globules. Mere pressure with the fingers will divide this liquid metal into globules so small that they lose their bright lustre and become grey. When sublimed in a tube some of these have been measured and their lustre and opacity determined, when they did not exceed the 20,000th of an inch in diameter.

2. A piece of gold may be hammered into leaf so thin that a book of the leaves, only an inch thick, would contain 300,000 of them. It would thus take about 1800 of them to make the thickness of ordinary paper. Yet each leaf is so perfect that, when laid on any surface, it gives all the lustre of solid gold.

By means of phosphorus placed on a solution of gold, this metal may be reduced to such a state of tenuity that its particles are suspended in water, and they give to the water by their transparency a blue, green, or ruby colour, according to the degree in which they have been split by the action of phosphòrus. From the experiments of Faraday it appears that the ruby liquid presents gold in its finest state of division. He estimated that in this state the particles of gold formed only the 500,000th part of the volume of the fluid. If the rays of light from the sun are thrown into this ruby liquid by means of a double convex lens, the minute particles reflect the light and show their presence by the production of a cone of gold in the fluid.

Platinum, the heaviest metal we have, can be drawn into wire much finer than the web of the spider. A single grain of it can be drawn into a mile of this wire, and seven ounces of it would reach from London across the Atlantic to New York.

Glass, which we usually consider so brittle, may be drawn into thread rivalling silk in softness and beauty.

A thread of the finest silk that is used in sewing is not single, but is composed of many hundreds of the threads that the silk-worm spins, which are said to be about the 2000th part of an inch in thickness. Extremely fine as these are, they are not so delicate as the spider's thread, for one-eighth of an ounce of the latter would reach from London to Edinburgh, or 400 miles.

One-eighth of a grain of indigo dissolved in sulphuric acid will give a well-marked blue colour to 300 ounces of water. This is in about the proportion of the millionth part of a grain to every drop of water. Müncke calculated the size of the minutest visible particle of indigo from the dilution of a measured quantity of the blue-coloured solution. He estimated it at the five hundred billionth part of a cubic inch!

A grain of musk will scent a room for twenty years. During all that time it must have been sending forth its particles in all directions, and yet it will have lost but very little of its weight.

By acute sense of smell the dog detects some material trace of his master as he tracks his footsteps, it may be for miles.

Still more minute are the divisions of matter that the microscope has revealed. It shows us that a drop of blood owes its colour to a multitude of very minute bodies (or *corpuscles*) of a round or egg shape, which float in a colourless liquid called serum. In human blood they vary from the 2000th to the 4000th part of an inch in diameter.

The microscope also shows us that a drop of water is a globe, in which thousands of tiny creatures (or *animalcules*) may live and move and have their being. And yet the water is not composed of living beings; it is made up of two gases, and we may have it without a trace of life. In a single drop some hundreds of these animalcules may have their birth, their food, their home, live their short hour of life, and die. Our mind fails to conceive, and almost to believe, such minute embodiment of life and possibly of pains and pleasures.

Nor yet have we reached the minimum of matter. Every addition to our power of vision only unfolds a new part of the same diorama; and if there be a limit to the subdivision of matter, it lies far beyond the line of our perception. For the smallest animalcule has organs of digestion and circulation necessary to the maintenance of its life. The *monas crepusculum*, or twilight monad, is considered to be the smallest of all living creatures. The globular body of this carnivorous animalcule sometimes does not exceed the 16,000th part of an inch in diameter

"*The Minima of Matter.*"

3. Many have thought that this diminution must of necessity go on for ever, and that there can be no limit to the divisibility of matter. But, besides the destruction of all definite conceptions which this involves, there are many strong reasons, drawn from the most varied phenomena of nature, for believing that every substance is made up of minute masses or molecules, which we are either utterly unable to break up, or which when broken up give two or more molecules quite different from the original.

We cannot see or handle a single molecule so as to put this directly to the proof. But the whole science of modern chemistry is founded on the conception of definite ultimate parts, and on the assumption that if any alterations take place in a mass, in precisely the same proportion, whatever quantity of it we try, it must be the result of similar alterations in these little masses or molecules.

"*Matter imperishable.*"

> **4.** When, then, we find that all matter is indestructible, and that we can no more put the smallest drop out of existence than we can create it, we have a confirmation of the theory which supposes the ultimate particles to be atomic or indivisible.

We may melt gold, and even make it pass into the form of an invisible vapour: but there ends the power of heat, the most potent analyser that we have. The natural conception of what takes place is, that the heat can separate the piece of gold into a vast multitude of minute portions, so that each is free from the company of its fellow, and at liberty to move in any direction; but that neither it, nor any other power we know, is capable of separating the molecules themselves.

5. By a chemical process, we may break up water little by little into two gases—oxygen and hydrogen—which separately bear no resemblance to the compound formed by their union: and, whatever quantity of it we take, we always get eight times the weight of oxygen that we get of hydrogen, though twice the quantity of the latter by bulk. Knowing then that, bulk for bulk, oxygen is sixteen times heavier than hydrogen, we conclude that each ultimate molecule of water is formed of two molecules of hydrogen and one of oxygen.

But by no process can we break up these gases; they may be subjected to the fiercest heat, and they will be as ready to form water again as ever, without the loss of a single particle. We picture, then, their elementary parts as themselves incapable of division by any of the forces at our command, or that have ever been in operation in the universe around us.

6. For if we take hydrogen from the bowels of the earth, where for thousands of years it has slumbered unmolested, and if we take it from the bosom of oxygen, in whose embrace it may have been for ages, and with which as water it may have lashed the shores of ocean or swept across the fields of air ten thousand times, it is precisely the same in all its properties.

Whatever may have been the history of the hydrogen and oxygen atoms, however many transformations and changes of partnership they may have had, the molecules of the one are as perfect to-day as centuries of centuries ago. Change of their positions is all that any natural or artificial process can effect; and by no changes can they be in the least worn or destroyed.

"*Atoms—Molecules.*"

7. Substances that cannot be broken up, or whose molecules are indivisible, are called *elementary substances*, *simple or chemical elements:* and their molecules are called *atoms* (i.e. indivisible parts). Thus all molecules are not atoms, though all atoms are molecules.*

A molecule of common salt is the smallest possible portion of the substance salt, but it consists of one molecule of chlorine, tied up with one of sodium, each of which, so far as we know, is an atom.

8. Every known substance has been found by chemists to be composed of one or more of sixty-five different kinds of matter, or elements. These chemical elements are such as gold, silver, platinum, copper, iron, oxygen, hydrogen, nitrogen, chlorine, carbon, sulphur, phosphorus, &c.

So far as at present known, no amount of heat will resolve any one of these, and no kind of alchemy will transmute the one into the other. An atom of gold is altogether different from one of copper or iron, different in size, and weight, and shape; and each atom has an independent imperishable existence.

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* Atom (from ἀ and *τεμνειν*, which cannot be cut or divided) and molecule (from *moles*, a mass, *molecula*, a little mass) are not synonymous. As applied to elementary substances an atom represents the smallest quantity of an element which can enter into combination, while a molecule represents the smallest amount of it which can exist in the free or uncombined state.

9. How sixty-five kinds of matter should, by variously combining, form the endless diversity of things and appearances which our globe presents, is not without analogy. All the words, all the literature of the English tongue, is formed out of twenty-four letters, and all the letters of the multitude of tongues on the face of the earth are not more in number than the chemical elements. Even more wonderful is the fact that all the words of the English, or any other language, may now be signalled along a telegraph wire by combinations of only *two* different signals, a long and a short one.

10. Though the complete discussion of the facts upon which the molecular theory of matter is based, belongs to chemistry rather than natural philosophy, yet there are many physical arguments that favour this view, derived from several of the departments of natural phenomena. These will be considered in a subsequent portion of the volume, as they are not of a sufficiently elementary character to be introduced in this place.

"*Matter extended or impenetrable.*"

11. The very simplest idea that we have of substance is that it is *extended*, or occupies space. No two portions of it can occupy the same spot at the same instant.

Though it is usual to give this as one of the universal properties of matter, and call it *impenetrability*, this implies really no more than is contained in the very notion of matter.

When we drive a nail in a door, the particles of the nail do not *penetrate* the particles of the door. We merely push the latter aside and put the nail where the wood was an instant before.

So pushing a bottle, mouth down, into water will never fill it; as the bottle is not empty but contains air, and there is no way for the air to escape so that the water may take its place. In a vacuum it would fill as readily with its mouth down, as with its mouth up.

12. It is of course the atoms or molecules that are really impenetrable. If we take two measures of hydrogen, and one of oxygen, and apply heat, the gases will rush together with an explosion, and occupy only two measures in their new form of water vapour. The penetration is however only apparent. Between the hydrogen molecules there is more than room for the oxygen atoms, and the two together are contented with the original accommodation of the hydrogen.

"All matter gravitates."

13. There is another property which constantly and inseparably accompanies matter, and which we are equally powerless to control. This is the power of *attraction* or *gravitation* according to which all matter draws and is drawn by all other matter. Every particle is invested with it, and by its power the huge balls of matter that roll through space are bound together. So inalienable is this property of gravitation from matter that we estimate the *mass* or quantity of matter in any case by the weight; and in chemistry an increase or decrease of weight points to an addition or withdrawal of matter. Of the nature of the invisible cords by which this attraction or pulling takes place we are as yet ignorant, though we know the laws or mode according to which it operates. There are many familiar instances of attraction, or drawing of matter from a distance without any apparent medium to transmit the action; and it is just possible that they may all be but modifications of this universal attribute of matter.

"Weight is the resisted attraction of the Earth."

14. When we drop a stone we say it falls down by its weight; and a person on the opposite side of the globe would say the same, though there the stone really falls up, if here it falls down. People in New Zealand stand with their feet against ours, like flies on opposite sides of a pane of glass, and hence they are called our *antipodes.*

Weight therefore is merely the pulling or attraction of the earth on bodies at its surface, and is the conjoint effect of the gravitating power of all the parts which compose our globe.

It acts as if the whole power of the earth were condensed at its centre, and the vertical, or line in which a plummet hangs or a stone drops, points at each spot over the globe towards that centre.

15. It is owing to this general attraction that our earth itself is a globe; all its parts being drawn towards each other, that is, toward a common centre, the entire mass assumes the spherical or rounded form. The sun, the moon, and the planets are also round, indicating the influence of the same law.

16. The drawing influence of our earth is not confined to its immediate vicinity, but reaches to the confines of the universe. It serves as a cord to keep the moon in its course around us ; as the sun's attraction restrains our globe from flying off like a stone out of a sling.

In every case, however, we must remember that the pulling is mutual; the moon exerts the same pull on the earth that the earth does on it; only the earth being so much the larger is comparatively but little influenced.

17. If we suspend two balls of lead near to each other, the same power is at work between them as between these huge balls we call worlds. The power is inconceivably less because the discrepancy in the amount of matter is so great. Still, what we want in matter may be supplied to a certain extent by bringing the balls nearer to each other; and with delicate suspension and means of observation we can detect an unmistakable influence.

Again, if in place of bringing one of the balls near to another of the same size, we can suspend it near to a huge mass, such as the precipitous side of a lofty mountain, the effect is not so insignificant ; there is a marked leaning of the suspended ball from the vertical towards the mountain. This was proved by Dr. Maskelyne from actual trial on the mountain Schehallion in Perthshire.

" *Law of gravitation of all matter.*"

18. The conditions on which depends the intensity of gravitation —as well as of light, magnetism, sound, or any other influence spreading uniformly from a centre—may be well illustrated by taking the case of light. Illuminating power is dependent, first on the extent of the light-giving source. If we double a gas flame we get double the amount of light. Two candles together will give twice the light of one of them at the same distance, and will cast twice as strong a shadow. But, again, we can see to read as clearly with one candle as with two, if the single flame be brought nearer us than the double flame. And one candle flame a yard off will give us the light not of two but of *four* similar flames two yards away, so that a decrease of distance more than compensates for a decrease of flame at the same rate. The reason of this is manifest from the following illustration.

19. A board a foot square, represented in fig. 1 by A B, placed at any distance from a candle at C, will just shadow a board, E D, of two feet square placed at double the distance, and one of three feet square, L K, placed at triple the distance. But E D will have *four* times as much surface as A B, because the former is both

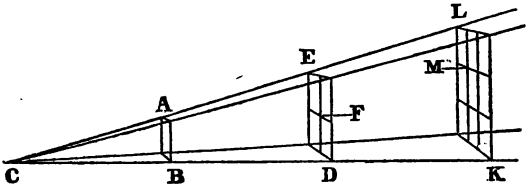

Fig. 1.

twice as long and twice as broad as the latter; and the board, L K. of three feet square, will in like manner have nine times as much surface as A B. Thus the light that A B would catch will be spread over four times as much space at E D, nine times at L K; and, consequently, it is only one-fourth as strong at double the distance, one-ninth at triple the distance, one-sixteenth at four times, and so on.

So if we had a bell ringing at C, the amount of sound that would be caught by an ear-trumpet with an opening of, say, one square foot, placed at B, will have spread out, at double the distance, over four times the space; and the ear-trumpet there would catch only one-fourth of the sound it caught at B, and therefore the sound would be only one-fourth as strong.

In more technical language the law is expressed, "*The intensity varies inversely as the square of the distance;*" that is to say, the intensity of light, sound, gravitation, &c., *increases* or *decreases* at the square of the rate that the distance *decreases* or *increases.*

20. Accordingly, what weighs a thousand pounds at the level of the sea weighs considerably less at the top of a mountain or when raised in a balloon, as is proved experimentally by a spring balance or other means.

Astronomical tests show that the amount of the earth's attraction on the moon is diminished according to the same law. The moon is about sixty times farther from the centre of the earth than we on its surface are; thus the force with which the moon is drawn to the earth is only about 1–3600th of its weight at the surface of our globe.

21. The gravitation existing between two masses or quantities of matter, then, depends on their size and distance. When they are small masses, such as two drops of water or globules of mercury, their mutual attraction will be inappreciable compared with that of the overpowering mass of the earth, unless, indeed, by bringing the drops sufficiently near we might atone for deficiency of matter. Such an attraction between small bodies does actually appear when we bring them very close together, and it is not impossible that it may be the same gravitating power in a different guise at the other extreme of nature.

Whether this may be proved or not, we shall adopt the ordinary distinction, which gives to attraction different names according to the distances at which it acts.

22. GRAVITATION is the attraction common to all matter when it acts at great or sensible distances, as between the moon and the waters of our earth, &c. It is incessant in its operation. No matter can be conceived to exist without it.

COHESION is the attraction between molecules of the *same* kind, binding them into masses, which must be overcome when we break or disintegrate a body.

Adhesion (including CAPILLARY ATTRACTION) is the attraction which exists in various degrees between *dissimilar* kinds of matter, as is illustrated in a marked degree by *cements.*

ATOMIC ATTRACTION is that which binds atoms together in groups or molecules, and is the ultimate cause to which we can as yet assign any phenomenon.

(There are other species of attraction called *Magnetical* and *Electrical;* but as they are not possessed by all bodies, nor at all times by the same body, they do not come under this group of common kindred attractions.)

Gravitation has been already considered sufficiently for the general purpose of this section. We shall now examine the part played by the other attractions in the production of the material appearances around us.

23. COHESION *is the attracting quality by which a number of similar molecules are held together so as to form one mass.*

A porter, whose work is to lift and carry weights, has to fight with the power of gravity; but the woodman who fells a tree, the blacksmith who files a piece of iron, the turner who shapes legs of tables and chairs, all gain their livelihood by a constant struggle against cohesion.

24. As might be expected, the limits within which this molecular attraction appears are extremely minute. The gravitation between two metal balls of three inches diameter cannot be detected till the balls are approached almost to touching; and these are worlds in size compared with molecules. If, then, there is any correspondence between the attractions of gravitation and of cohesion, the appreciable range of the latter will be very much less than the breadth of a molecule, which we have seen is so small as almost to defy calculation.

From this argument, as well as from experiment, it appears that the cohesive influence of a particle will not extend beyond the breadth of a contiguous particle; and, consequently, that when two masses are made to cohere, it is merely the upper or surface molecules that are brought into play.

25. For cohesion of two masses we must, therefore, bring a sufficient number of molecules face to face, as well as press them very closely together. This done, we need no glue or paste to effect the junction. But this is not so easily done. For a surface that we deem smooth may be really so rough that, when we apply it to another, the two touch only at a few projecting points, whose cohesion will of course be insignificant.

Two pieces of common glass, though they appear quite smooth, will not usually cohere. Yet glass polishers are familiar with the fact that sheets of flat and highly polished plate glass laid on each other often stick together so that they cannot be separated without fracture.

26. The following are a few examples of the sufficiency of these conditions for perfect cohesion :—

Similar flat-faced portions being cut off with a clean knife from two leaden bullets, and the fresh surfaces being well pressed together, the bullets will cohere, sometimes as firmly as if they had been cast in one piece. This is not owing to atmospheric pressure by the displacement of air between the two surfaces of lead, for the bullets cohere with equal firmness when placed in the vacuum of an air-pump.

Fresh-cut surfaces of caoutchouc (or india-rubber) may be united in a similar way. If a sheet of it be folded, and a strip cut off near the fold by one stroke of a pair of long scissors, the strip, by pressing together the two surfaces, will become a perfect tube with the seam scarcely visible.

Clean sheets of lead or tin may be united by simply pressing them together between the powerful rollers of a flatting-mill.

The restoration of cohesion is beautifully seen in the gilding of china. A line or figure is drawn on the china with a mixture of oxide of gold and an essential oil. The article is then heated, whereby the essential oil and the oxygen of the gold are expelled, and a red brown pattern remains. This consists of pure gold in a finely divided state and without lustre. By rubbing it with a hard burnisher (hæmatite) the particles of gold are made to cohere and reflect the rich yellow colour of polished gold.

By sufficient pressure brick-dust may be formed into tiles, agate-dust into buttons, broken ice into solid lumps, and slate-dust into rods for pencils.

Thus, too, sandy matter deposited at the bottom of the sea, and undergoing there the pressure of great depths for ages, is formed into the solid rocks which can be used for building.

27. Surfaces may, however, appear to the eye to be in contact when they are not actually so. Newton found, during some experiments on light, that a convex lens, or a watch-glass, laid on a flat piece of glass does not touch it, and cannot be made to touch it, even when compressed with a force of many pounds.

If such be the case with a smooth hard substance like glass, which does not readily tarnish, we can easily see how much more difficult it will be to bring within cohering distance two metallic surfaces, which speedily acquire a spongy oxidised film on their surface when exposed to the atmosphere.

This is the reason that the metals require, almost all of them, to be heated or melted before they will cohere in a solid mass. The oxidised portion then rises as dross to the surface and allows free contact of the pure metals; the intense heat also expels the air, which would serve to prevent contact in the cold state. In the art of soldering, by which metals are made to cohere, borax, sal ammoniac, and other fluxes are used for the purpose of dissolving the oxides of the metals produced by heat, and thus bringing into contact perfectly clean metallic surfaces. They then cohere firmly.

28. The degree of cohesion among the particles of a body will depend on their mutual distance; and this, as we shall consider more particularly afterwards, will vary with the amount of heat or heat-motion present in the mass.

Meantime we must anticipate one of the subjects to be treated hereafter, so far as to explain that heat is to be regarded as a minute vibration of the particles of a body, which is never wholly absent, but which may be increased or diminished within wide limits. According to this theory, when we add to the heat of a body by any means, we merely increase the agitation amongst its molecules. These will therefore elbow each other more widely apart, and the result will be an increase in the apparent bulk of the body. Hence it is that, as a general rule, *increase of heat expands bodies and lessens their internal cohesion.*

29. Cohesion and heat or heat-motion, then, are the two antagonists in nature, on whose relations the physical condition of all bodies depends, and whose relative changes determine the most obvious distinction of substances—the distinction, namely, into *Solids*, *Liquids*, and *Gases*.

A SOLID is a collection of particles cohering firmly together so as to keep their positions with respect to each other practically unchanged. We are not to suppose that the particles are *absolutely* fixed together and devoid of all motion, but only that the heat or quivering motion is of small range, and the cohesion is the resistance offered to the particles being pulled altogether out of place, or the limit of their motion being exceeded. In solids we may say, then, that the cohesion entirely overpowers the opposing heat-vibration.

A LIQUID is a body whose particles are all balanced more or less exactly between these two opponents, and being, as it were, inclined to neither party, are perfectly free to move amongst each other. The particles are just on the border of the territory of cohesive attraction.

A GAS, lastly, is a body whose particles have been separated beyond this limit by heat-motion imparted to them, and, being practically freed from all restraint, are moving to and fro amongst each other in ceaseless confusion. Motion is here predominant, and the power of cohesion altogether in abeyance.

"*Cohesion in solids.*"

30. As cohesion plays the most important part in solids, so its modifications produce in them the most noteworthy varieties of character. Thus differences of cohesive power, coinciding with differences of molecular structure, and probably of the shapes of molecules, occasion the various physical properties in solids known as *porous*, *dense*, *crystalline*, *hard*, *brittle*, *elastic*, *pliant*, *malleable*, *ductile*, *tenacious*. We shall consider in detail the peculiarities on which these several physical qualities depend, as a knowledge of them as well as of the materials, where each of the properties is specially developed, has already proved of the utmost value to the arts and to civilisation.

"*Porous*."

> **31.** There is no body, even the most dense, whose molecules are everywhere in absolute contact; and there will thus be intermolecular spaces or *pores*, which may be filled with air or any fluid whose molecules are fine enough to enter the spaces.

A considerable quantity of water may pass into a bit of chalk, a lump of sugar, or even a piece of stone, and be hidden away among the pores without increasing the bulk. Chalk is said to absorb as much as a third of its own bulk of water.

A kind of agate stone, called *hydrophane*, is opaque until wetted, when its pores get filled with water (even to one-sixth of its weight), and under these circumstances the stone becomes translucent, giving a passage to light.

32. Pores exist in the densest metals, for by strong compression they may be squeezed so as to occupy less bulk, and this can only be by bringing the molecules nearer and lessening the intermediate spaces.

Pressure will drive water through solid gold or copper, as was seen in the famous Florentine experiment, where a hollow gold ball, being filled with water and strongly pressed by a screw to test the compressibility of water, was found to perspire all over. We have by a similar experiment seen water thus forced through a copper ball and deposited on the outside as a fine dew.

Filters are bodies, suitably shaped, whose pores are sufficiently large to allow the passage of water, or other liquids, but small enough to detain any solid impurities.

33. Animal and vegetable bodies are the most porous, for internally they are a multitude of interlacing channels whereby, during life, the nourishing fluids may circulate.

Bone is a tissue of cells and partitions, as little solid as a heap of empty packing-boxes. Wood is a congeries of parallel tubes or fibres like bundles of organ pipes.

Condensed wood is now prepared for various purposes—as for making the pins used in wooden ship-building, for wedges used in fixing iron rails to the chairs—by compressing it laterally to about half its original bulk, and so making it approach the solidity of metal.

34. It is the buoyancy given by the air contained in its pores that makes wood lighter than water; for if a log of wood be exposed to the pressure of a great depth of ocean, its pores become filled with water, and it sinks as readily as stone. Thus it was with the boat of a whale-fishing ship which had been dragged far under water by a whale: when being afterwards drawn up by the rope of a harpoon, it was supposed to be bringing a piece of rock with it.

35. Petrifaction furnishes a striking proof of the existence of pores in such bodies as wood or bone. The usual explanation given of this natural formation is that at some remote period, the wood or bone had been immersed in water, which contained silicious or flinty matter in solution, and that this, penetrating through all the pores of the mass, hardened on the decay of the vegetable or animal matter, and at the same time displaced it. In a fossilized substance, then, we have a fac-simile, an actual cast, moulded by nature in limestone or flint, of the whole system of pores that existed in the animal or vegetable body during life.

"*Dense.*"

36. The quantity of matter which we estimate by its weight, existing within a given space—such as a cubic foot or a gallon—may be very variable.

Thus a cubic inch of lead is nearly forty times heavier than a cubic inch of cork.

If a wine-glass be filled with mercury, we are surprised when we lift it for the first time; it is as heavy as thirteen and a half times the same quantity of water.

37. We commonly estimate the quantity of matter in a body by its *specific gravity*, or weight, compared with that of an equal bulk of some specific or standard substance, which we adopt as the unit of density. Pure water being so easily procurable at all times and places, and being uniform in its composition, has been almost universally selected as the standard of reference.

38. When, therefore, we say that the metal platinum has a specific gravity of 22, we mean that a cubic inch of it is twenty-two times as heavy as a cubic inch of pure water. So we say gold has a specific gravity of 19; mercury, 13½; lead, 11; iron, 8½; copper, 8; common stone, about 2½; wood, from ½ to 1½; cork, ¼; and so on.

39. Density must depend, first on the weights of the individual molecules, and secondly, on their degree of approximation, i.e. on the number which are packed within a given bulk. Hydrogen molecules are lighter than those of any other known substance; and hence chemists take this gas as the unit of reference, to avoid fractions as far as possible in the expression of specific gravities of gases and vapours.

Secondly, density must depend on the temperature, for whatever affects the nearness of the molecules of a body must of course alter its density. Now, as a general rule, heat expands bodies and separates their molecules more widely: hence heat, as a rule, lessens the density by increasing the bulk.

As our standard of density, then, will itself vary according to the degree of warmth or temperature, we must, for accurate comparison, have it at a certain fixed temperature—such as the freezing point of water—or we must know what allowance to make for the difference of warmth.

"*Crystalline.*"

40. Cohesive attraction is not, in most cases, the same all round a molecule; but like the poles of a magnet, it seems to lodge nearer certain sides or ends of the molecule. Thus when the particles are free to move in any direction, and to follow their natural tendencies, they generally assume a more or less regular arrangement, or a form we call crystalline.

Moisture, or watery vapour, freezing on the window-panes, shows beautifully this selective attachment of the particles in passing from the liquid to the solid state.

A flake of snow consists of groups of crystals of a stellated form, in which all the angles are of 60°. Each crystal consists of six prisms radiating from a centre, and exhibits a symmetry of formation as regular as that of a fern-leaf, or a bird's feather.

Water beginning to freeze, shoots delicate needles across its surface: these thicken and interlace till the whole mass becomes apparently solid, but the crystalline arrangement remains, and may be detected by allowing a lump of ice to remain for some time in water at, or a little above, 32°.

This crystalline structure of solids is well illustrated by immersing for a few hours a rough block of alum in a nearly saturated solution of alum in water. It will be found that the alum, instead of dissolving uniformly, will appear as if dissected, traversed by numerous lines and smooth surfaces, always taking the form of the regular octohedron, or eight-sided crystal, which is the natural form of crystallised alum. This demonstrates that the cohesive force is strongest and best able to resist solution in the direction of the crystalline planes.

When any solid, such as a metal, is in the liquid state, its molecules are not within perfect cohering distance; but as it cools these approach gradually, and in the way which their polar attraction dictates. It becomes solid first on the outside of the mass, as it cools from without. If, before the cooling is completed, we break the crust and pour out the remaining liquid, the curious internal crystalline structure will be displayed. This is well seen in melting the metal bismuth in an iron ladle. When the melted metal has solidified on the surface and at the sides, the fluid portion is poured away and the bismuth will be found crystallised in regular cubes striated on the surface. Sulphur may be obtained crystallised in prisms by a similar process. Hollow balls of crystals of carbonate of lime and quartz have been thus produced naturally. They are called *geodes*. What is called the grain of a metal is the result of this action.

41. The process of crystallisation is most readily exhibited by the solutions of salts. Saltpetre, glauber-salt, copperas (or green vitriol), sulphate of copper (or blue vitriol), alum, borax, and any other salt the solubility of which is much increased by heat, are well adapted for crystallisation. When dissolved in hot water, and the water is allowed to cool, or slowly to evaporate, the salt is deposited in beautiful solid crystals, each salt having a special and invariable form of crystal, with sharp angles and flat polished faces.

If any such crystal be broken, the broken surface appears to the microscope as if regular layers of particles had been disturbed (like a broken stack of bricks or pile of bullets), and the deficient portions of the crystal will be exactly replaced by putting it in the evaporating solution.

42. A drop of a solution of sal-ammoniac in water, placed on a slip of glass, and allowed to evaporate, produces the most beautiful arborescence.

If a piece of copper is thrown into a solution of nitrate of silver, the copper is dissolved, while the silver is rejected. During this exchange the silver slowly forms into a beautiful shrub or tree, resting on the remaining copper as its root. This formation is called the *arbor Dianæ.*

43. All the precious stones have a crystalline structure, and can be well cut and polished only parallel to the natural faces of their crystals. This is called *cleavage.* Thus a diamond can only be split in layers corresponding to the regular octohedron. The basaltic pillars of the Giant's Causeway in Ireland, and of the Isle of Staffa, which appear like a garden supported on magnificent columns in the midst of the ocean, are natural crystalline arrangements rivalling in regularity and beauty any human work, and in grandeur so surpassing, that superstition might well ascribe them to the handiwork of giant architects.

44. No better example can be given of the power of co-operation of the small particles of matter, than the force with which they unite when crystallisation takes place.

Water, with one or two other substances, becomes more bulky on solidifying : and the united effort of the small molecules of water to arrange themselves in a crystalline form is such as to burst the strongest vessels. A cannon, filled with water and firmly plugged at the mouth, has been burst when the water became frozen. This agency contributes to the gradual breaking down of our Alpine summits, and the destructive falling of their fragments into the valleys.

45. There is an immense variety of crystalline forms, though they may all be referred to a certain number of typical figures or *systems,* which may be found in any text-book on *mineralogy,* the science to which the subject of crystallisation specially belongs.

" *Amorphous.*"

46. When bodies possess no regularity of structure, they are termed amorphous—that is, without definite form.

This may arise, however, not from any want of polarity in the particles, but simply from the circumstances in which they are placed, and the very same molecules may be found at one time amorphous and at another crystalline. Chalk and Iceland spar are similar in composition—carbonate of lime or carbonate of calcium. Chalk is soft, white, opaque, is easily broken in any direction, and has no crystalline form. It is in the amorphous or shapeless condition. Iceland spar is seen in beautiful transparent crystals of a rhomboidal form : it is colourless, hard, brittle, and breaks only in the three directions of the faces of a rhomboid. Again, iron and all metals are devoid of structure when in a molten state, but become crystalline on cooling : and indeed, as a rule, all crystals descend from an antecedent amorphous condition of fluidity. For the perfect development of the crystalline state, it is necessary that the particles should be all free to move, and this is effected by solution, fusion, or sublimation.

47. The operation of crystallisation is very extended in the inorganic world especially, and leads to peculiarities of structure that usually appear under the guise of special names—as "*hard*," "*brittle*."

"*Hard.*"

48. One body is said to be harder than another when we can scratch the latter with it.

The hardness is not due, as might at first be supposed, to mere density, but to the force with which the molecules retain their polar or crystalline arrangement. Gold and mercury are both among the heaviest of metals, and yet they are also among the softest of them.

49. Mineralogists have a number of type-substances, whose degrees of hardness are very uniform, arranged so as to form a scale of reference for determining the hardness of any other body. In the following or Mohr's scale, which is commonly adopted, the relative hardness of each of the ten substances is cited by the number which gives its place in the list :—

1. Talc.
2. Rock-salt.
3. Calc-spar.
4. Fluor-spar.
5. Apatite.
6. Adularia-felspar.
7. Rock-crystal.
8. Prismatic topaz.
9. Corundum.
10. The diamond.

To determine the hardness of any mineral, we simply try, beginning with the hardest, which of these ten it will just scratch ; in this way we can say between which two degress of hardness it lies.

50. Diamond, which is a crystalline form of carbon—the same substance as charcoal—is the hardest of known substances. It cuts or scratches every other body, and can be polished only by its own dust : yet it is but about one fourth part as heavy as gold. Glaziers use a small point of diamond, formed by the natural edges of a crystal, as a knife for the cutting and shaping of glass.

The piercing through hard rocks—such as was done in the recent cutting of the Mount Cenis tunnel—is now effected by means of diamond-pointed drills, driven at a very high speed by powerful engines.

Crystals of quartz, and common flint, will also scratch glass ; and even a piece of hard steel, such as a corner of a newly-broken triangular file, may serve in place of a diamond for writing on glass.

51. Hardness depends, however, on some circumstances not yet thoroughly understood ; for the same body when subjected to different treatment, may be hard or soft.

Steel owes its hardness to *tempering*, that is, to a sudden cooling in oil or water when the steel has been heated to a certain temperature. If the same steel be allowed to cool slowly, it retains all the softness and flexibility of iron. Iron does not possess the property of being hardened by sudden cooling. The discovery of this fact respecting the tempering of steel is, perhaps, second in importance to few discoveries which man has made ; for it has given him all the edge tools and cutting instruments with which he now moulds every substance to his wishes, and to which he owes all his modern mechanical improvements. A savage would work for months with fire and sharpened flints in order to fell a tree or carve a rough canoe, when a modern carpenter with his tools of hard steel could accomplish the same object better in a few days.

" *Brittle.*"

> **52.** It is a general rule that very hard bodies are also very brittle or liable to break. The special intensity of cohesive power which constitutes hardness, seems to be accompanied with a condition which allows the molecules no play of position.

A comparatively slight force across the direction in which the cohesion is concentrated, will rupture the body, especially if the force be applied sharply.

Glass scratches pure iron—proving that it is harder than iron ; yet glass is the very type of fragility.

Hard-tempered steel is very brittle ; those steel chisels and tools used for shaping stones and metals, require of course to be exceedingly hard ; but they thereby lose in strength and are often broken.

Cast-iron, a complex crystalline substance which is much harder than malleable or wrought iron, is correspondingly more brittle : while soft iron and steel are the toughest materials in nature.

53. In general the fragility is greater the more sudden the change of temperature to which any material has been subjected. Glass vessels, if rapidly cooled when blown, are so brittle that the slightest scratch with flint or a grain of sand will break them.

Rupert's drops are tadpole-shaped pieces of green bottle glass, which have been formed by melting the glass and allowing it to drop into cold water. Only the surface or skin of the glass in this case has had time to solidify; the interior particles, not having settled in their natural position, are in such a state of tension that the mere breaking off of the tail of the drop is sufficient to cause the whole to fly into a thousand pieces; but a hard blow may be given to the thick part of the drop without breaking it.

Brittleness, in the making of metallic casts or of glass vessels, is obviated by the process of *annealing*, i.e. by re-heating and very slow cooling, which may have to extend over days or even weeks, that the articles may be fit for handling and for resisting ordinary changes of temperature.

"*Elastic.*"

54. An elastic body has its molecules so balanced between the extreme positions of no cohesion on the one hand, and of actual contact on the other, that they admit of a certain play under the action of any force, always returning to their original position when the strain is removed.

Elastic bodies vary much in the amount of this play of their particles, and also in the readiness and extent of their return towards their first arrangement.

Thus, india-rubber is very elastic, for it yields far; but it is by no means perfectly so, for when stretched much or often, it becomes permanently elongated. Glass, again, is almost perfectly elastic, though only within small limits; for it will retain no permanent bend; but, unless in very thin plates or in fine threads, it will not bend far without breaking.

A steel sword, or any long strip of good steel, may be bent till its ends meet, and yet when allowed will return to perfect straightness; a piece of inferior steel, or of any other metal, will either break in the bending, or retain a bend. A steel watch-spring, although so much and so constantly bent, resumes its original form when set free at the end of a century; yet often, from some invisible flaw it will suddenly give way while in action.

The elasticity of steel is of the greatest utility: time-pieces, gun-locks, door-locks, carriage springs, railway buffers, steel pens, spring balances, are some of the hundred cases where it finds application.

55. When a billiard-ball strikes another, or rebounds from a marble slab, there is more than a mere meeting of the surfaces at a single point. For if the slab be slightly smeared with oil or ink, a large round spot will be left on both the slab and the ball, proving that there had been a sudden flattening of the ball at the instant of striking. It is the force with which the particles of ivory are drawn back into their original position that throws the ball up in the air again, or causes it to rebound.

The elasticity of ivory is so good, that billiard-balls scarcely lose even their polish by long use, though the touching parts yield at every stroke.

56. In bending a rod of steel or a plank of wood, we have to pull the molecules on the upper (or convex) side of the rod asunder, and to press those on the lower (or concave) side closer together. We are thus doubly resisted by the cohesion of the particles, and there are two forces conspiring to bring the rod to its original shape when we leave it to itself.

57. Elastic bodies may be either hard or soft; but the harder they are, then the less the extent of strain they allow within the limits of elasticity. If we exceed this limit, we produce a *set* or permanent change in the shape or size of a body. A sprain of a muscle, for example, is a stretch beyond the limit of its elasticity.

The hard bodies—steel, glass, ivory, stone, &c.—have a much smaller elastic limit than the soft ones, such as caoutchouc, silk, catgut, &c.

"*Pliant.*"

> **58.** Animal and vegetable substances have a cohesion called *pliability*, rarely met with in the mineral world, by which their fibres admit of sharp or sudden bending without fracture, as if they consisted of a chain of minute hinges or joints.

Silk, bladder, lint, hemp, skin, hair, &c., are very pliable, and owe their value chiefly to this property. Weaving and textile manufactures generally employ the various materials endowed with this quality.

The most remarkable example of this in the mineral world is afforded by *asbestos*, or *amianthus*, a fibrous mineral, which owes its name to another and still more remarkable quality, namely, that of being indestructible by fire. It has been even manufactured into gloves, jackets, and fire-proof clothing. It is a non-conductor of heat; so that a red-hot poker may be for a short time held in the hands covered with a thick asbestos glove. If strongly compressed, there is an unpleasant sensation of warmth felt between the seams. The Chevalier Aldini invented asbestos dresses in 1830 for the use of fire-men; but they were found to be too costly, a jacket costing fifty pounds; and they were so heavy, that if a man fell, he had great difficulty in getting up again without assistance.

"*Malleable.*"

59. The cohesive quality by which bodies allow of their being hammered into thin leaves or plates is termed *malleability.*

In malleable bodies, the molecules have no special disposition, but will cohere in any way, the attraction acting indifferently all round the molecules, so that they yield to force and glide about among each other without fracture, almost like the particles of a liquid.

60. Gold is the most malleable of all the metals; it may be hammered until it is reduced in thickness to the 300,000th of an inch. In this state it is transparent to light, allowing the green rays to traverse it. For gold-beaters the metal is first formed into rods; these are then rolled or flattened into ribands: the riband is cut into thin strips, which are hammered out to a great width; these are again subdivided, and lastly hammered out to the tenuity described. An alloy of gold with silver, in the proportion of 20 parts of gold to 22 silver (called lemon gold), is equally malleable. This may be reduced to the 300,000th part of an inch in thickness, and it is also transparent to light, allowing the reddish-purple or violet rays to pass through it. No other metals can be reduced to such a degree of tenuity. Tin is malleable, but the thinnest leaves are the 1600th part of an inch in thickness.

Dutch gold, an alloy of copper and zinc, may be brought by malleation to very thin leaves, sometimes mistaken for and substituted for gold. The thinnest leaves are, however, quite opaque, and do not allow any coloured light to traverse them.

Silver and copper may be hammered till rendered very thin. The coppersmith hammers a flat piece of copper into the shape of a vessel without crack or seam, and of uniform thickness throughout.

Iron becomes singularly soft and malleable when heated to redness. Under the forge hammer it takes any desired form almost as readily as potter's clay. Between rollers, it can be spread into sheets as thin as paper, or lengthened into uniform solid bars for railways.

Platinum is the only other metal which, like iron, is malleable or weldable at a red or white heat.

61. By the same, or an analogous property, metals such as copper, silver, gold, may be made, under the blow of the coining-press, to take impressions as delicate as those of sealing-wax from a signet-stone.

"*Ductile.*"

62. The most malleable bodies are not always the most *ductile*, or easy to draw into wire.

Both properties are, however, alike due to a *fluidity* of the molecules by which they may be moved past each other without loss of cohesion.

63. To form iron wire, a rod of iron, being reduced in size so as to pass through an opening in a plate of hard steel, is seized beyond the plate by strong nippers, and the whole rod is forcibly drawn through. It is thus reduced, of course, to the size of the opening, and is lengthened accordingly. By repeating the operation through smaller holes in succession, a wire may at last be obtained of the thickness of a hair.

A grain of gold has been drawn into five hundred feet of wire, and from a calculation made by Müncke, the diffusion of a known weight of gold over silver-wire may be carried to such a degree, that one grain admits of subdivision into ninety-five thousand millions of visible parts, i.e. visible under a microscope magnifying a thousand times.

Dr. Wollaston produced a wire of platinum only the 30,000th of an inch in diameter by the following ingenious process :—A small platinum wire was placed in the axis of a small cylinder of silver; the compound wire was then drawn out in the usual way so far as its ductility would admit. It was then placed in nitric acid; the silver was dissolved, and the platinum left in the form of a wire of about half the thickness of the thread of a spider's web. It could only be distinctly seen when heated to redness.

Platinum is thus the most ductile metal; after it come the other metals in the following order: *silver*, *iron*, *copper*, *gold*, &c.

Melted glass is very ductile. The workers draw or spin it into fine silky threads by merely attaching a point, pulled out from the mass, to the rim of a turning wheel; and a uniform thread is thus wound upon the wheel at the rate of many yards per minute.

"*Tenacious.*"

64. The power of cohesion with which a rod or wire of any material resists being pulled asunder, end from end, is called its *tenacity.*

Iron and its varieties possess this property in a most remarkable degree: and to this we owe those gigantic roofs, railway and suspension bridges, which are at once elegant and economical—altogether a feature of modern scientific engineering.

65. The following table shows that other materials are far inferior to iron in tenacity; we give the weight that can be supported by a rod of each having a cross-section of one square inch :—

Metals.

Cast steel	45 to 60 tons.
Best wrought iron.	25 to 30 "
Cast iron	6 to 13 "
Copper	9 to 26 "
Platinum	8 "
Silver	5 "
Gold	4⅛ "
Zinc	2 "
Tin, about	1⅓ to 2 "
Lead	1 "

Woods.

Teak	7 to 9½ tons.
Oak.	4 to 9 "
Ash	8 "
Deal	6 "
Beech	5 "

Iron, compared in this way, is from five to eight times stronger than oak.

Steel wire will support the weight of about seven and a half miles of itself. The Atlantic cable, which may often have to support great lengths of itself as it hangs from precipices in the ocean depths, depends for its strength on a sheathing of steel wires wound spirally round it.

66. Some animal substances have great tenacity: as—the silkworm's thread, which, though perfectly flexible, has a tenacity equal to that of brass wire, and three or four times that of hempen ropes of the same thickness;—the ligaments and tendons of the animal body, possessing at once great strength, elasticity, and pliancy, as the manifold needs of life obviously demand;—catgut, well known for its extraordinary strength, is formed from strips of the intestines of the sheep or goat, twisted and dried;—the hair or wool of animals twisted into threads and worked into the strong and beautiful textures of the loom.

67. So much for the varieties of character in solids corresponding to variations of cohesion. We pass to consider the manifestations of this attraction in liquids, for even there it is not wholly absent.

" *Cohesion in Liquids.*"

> **68.** In liquids the molecules are separated more or less nearly to the point at which cohesion ceases to be perceptible: compared with solids we may say they are devoid of cohering power; but when we come to examine minutely we find it otherwise.

Liquids may indeed have their molecules even farther separated by heating, but it is extremely difficult to say when they approach the line of no cohesion, because their transit across that line into the region of gas is so abrupt.

69. It is cohesion that draws together the particles of mist into dew-drops or rain-drops, and that moulds the silver globules of mercury. Melted lead, rained down from an elevated sieve, acquires the form of drops in its fall; cooling as it descends, it retains a spherical form, and becomes the beautiful lead-shot of the sportsman. If we dip a large pane of glass in water, and try to lift it out keeping its face horizontal, we find it requires considerably more exertion than if we take it out edgeways. The reason is, we have to overcome the attraction of the liquid molecules that have stuck to the pane for their neighbouring liquid molecules.

It is found that cohesion is greatest at the surface of a liquid, because there the attraction of the final layer of molecules is not divided as it is in the lower layers. A needle laid gently on the surface of still water will float, though bulk for bulk it is much heavier than the water, because its weight is not so great as to overcome the surface cohesion of the fluid. Light insects, for the same reason, may often be seen walking on water.

A striking example of the cohesion of liquids is seen in the soap bubble, which can be stretched to a great extent before this attraction is exceeded.

70. Considerable differences of cohesive power are observed in liquids. In *limpid* liquids, such as spirit of wine, naphtha, eau-de-cologne, &c., the mutual attraction of molecules is very feeble, and they display great mobility: we could never blow bubbles with them, and those we produce by agitation are very small, and merely momentary in duration.

Viscous liquids, on the other hand—such as glycerine, syrup, oil, sulphuric acid, &c.—are sluggish in their motions, being hampered by greater cohesion of particles. For this reason, too, drops of viscous liquids are much larger than those of limpid ones poured from the same phial mouth. Sixty drops of water fill the same measure as a hundred of laudanum when poured from a lip of the same size.

In the transition from the solid to the liquid state, bodies sometimes—but by no means generally—assume the viscous condition. A proper chemical compound, ice for example, passes, as a rule, suddenly from the solid into the liquid state; but mechanical compounds of ingredients that melt at different temperatures, as well as those metals which, like iron, potassium, or sodium, admit of *welding*, pass through an intermediate semi-fluid or viscous state before complete fusion.

"*Variations of cohesion in liquids.*"

71. Liquids, like solids, have differences of *porosity*, *density*, *elasticity*, and *hardness* or *compressibility*, corresponding to differences of cohesion.

"*Liquids porous.*"

72. If we mix a pint of alcohol or a pint of sulphuric acid with a pint of water, we get less than two pints of liquid from the interpenetration of the molecules.

A large quantity of gas may be forced into the pores of liquids without increasing the apparent volume. Thus the quantity of liquid in a soda-water bottle will not appear any less in bulk after the carbonic acid gas has passed off by effervescence.

"*Density of Liquids.*"

73. Liquids vary in density from the light alcohol to the enormously heavy mercury; and, as in solids, an increase of heat separates the molecules and reduces the density. Distilled water is the usual standard of comparison for the specific gravities of liquids. If its density be called 1, that of pure alcohol is ·8, and of naphtha, ·86 or ·9; of oil, ·9; of wine, ·99 to 1·03; of sulphuric acid (or vitriol), 1·8; of milk, 1·03; of sea water, 1·026; and of mercury, 13·59.

"*Elasticity of Liquids.*"

74. Liquids are perfectly elastic, only within very minute limits. They are so extremely difficult to compress that they were long regarded as absolutely incompressible; and no wonder, for the weight of 1000 fathoms, or over a mile of water, will compress that underneath only by the hundreth part.

In this sense, then, liquids may be called very *hard*, since they require an extraordinary mechanical power to squeeze their particles closer together. But so far as they are compressible, we have many reasons for inferring that they are quite elastic, or will recover their former volume on removal of the compressing power.

75. In air or gases, again, the vibratory motion of the particles entirely overpowers the cohesion, and we find little in them to illustrate this subject. They are the extreme of softness, and are perfectly elastic within enormous range; they may be squeezed to almost any degree, and yet always return to their original bulk when the pressure is removed. Some gases, indeed, have a smaller range than others, for they can be squeezed till they collapse into a liquid. But common air, and the fixed gases generally—such as oxygen, hydrogen, &c.—may be compressed indefinitely without passing into the liquid state.

"*Adhesion.*"

76. ADHESION is the attraction between a solid and a liquid, or between any different kinds of matter. We have many familiar examples of this:—

A finger dipped in water comes out wet: dipped in mercury it comes out clean and dry. The skin thus seems to have an attraction for water, none for mercury. But the want of attraction in the latter case is only apparent: for, if we touch a small globule with the finger, it will stick to it; though, if we bring it to touch another mass of mercury, the globule at once shows its preference for its kindred element, and is drawn away from the finger. This, then, is the true explanation of wetting: *the adhesion of the liquid to the solid is greater than the cohesion of the liquid.*

Gold and silver, dipped in mercury, will come out covered with it, showing that they draw it more powerfully than it clings together.*

If we are over-cautious in pouring from a tumbler or cup, the liquid may prefer trickling down the inclined side of the vessel to falling vertically. Hence the use of a projecting lip, that the quantity approaching the edge at one time may be a small stream, and its adhesion for the glass less difficult to overcome than that of a broad sheet of liquid. In pouring clean mercury from a glass, a lip is unnecessary, as the liquid has practically no adhesion for the glass.

77. As in cohesion, so in adhesion, only the surface layer of molecules is concerned: hence a mere film over a surface is enough to alter its adhesive power. Thus if glass be greasy, it will not be wetted with water; or, if we rub the hand over with lycopodium dust, we may dip in water and take it out quite dry.

"*Cements.*"

78. On the other hand, the introduction of a mere film of glue or cement may be sufficient to create a strong adhesion between two surfaces which otherwise cannot be made to attract each other. The value or power of a cement depends principally on the strength of its adhesive attraction for each of the substances to be united. Sometimes two plates of glass have been glued together so firmly by adhesion that part of the surface of one of the plates was torn off in the attempt to separate them. That this adhesive power is of more consequence than the mutual cohesion of the cement or glue is clear from the fact that the junction is always stronger with a thin than with a thick layer of cement.

No general theory can as yet be given, but we may trace very often some resemblance in the characters of the cements, and of the bodies they attach. Thus we cement stones with mortars, limes, &c., which are of a similar earthy nature; we use glues of an organic origin, such as common glue, isinglass glue, gum arabic, marine glue, &c., for joining pieces of wood, leather, paper, &c., all likewise organic; on the other hand, we cannot join metals with any of these, but only with metallic solders. There is difficulty in cementing together bodies of opposite character, such as glass and metal, with any powerful degree of cohesion. The rate of increase and diminution caused by heat in glass and metals is so different that, if the two bodies cohere at a high temperature they are separated on cooling. The metal contracts so much more than the glass that cohesion is destroyed. The only metal which can be united to glass is platinum, and the cohesion of these two substances is applied to various useful purposes in chemistry. This exception is explained by the fact that there is less difference in the rate of expansion and contraction of glass and platinum than of glass and other metals. We cannot lay down rules as universally true, of course; and it is possible, as with platinum and glass, that the similarity of character need only be one-sided, that is to say, one of expansibility under the action of heat. In soldering two metals of different kinds, for example, we use a solder intermediate in its degree of expansibility under heat, to the two metals: otherwise any change of temperature will destroy the joining. This must hold in every case of gluing or cementing; but there is most probably a further resemblance in nature, though we cannot as yet state it with much definiteness.

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* This arises from a chemical union of the fluid mercury with either metal forming an amalgam. Chemical attraction is here more powerful than that of cohesion.

79. It is more difficult than may at first appear to determine the amount of adhesion between a liquid and a solid. A plate of glass balanced at the end of a weighing beam and then allowed to come in contact with water, adheres to the water, and with much greater force than the mere weight of the water remaining attached when again forcibly raised. But this does not show the amount of attraction between the glass and the water, because we cannot detach the plate clean and dry; we merely find the force required to overcome the cohesion of the liquid.

80. We find adhesion existing between gases and solids, and between gases and liquids. A tumbler of spring water, after standing a short time in a warm room, will be seen to have its inner surface studded with minute spherules of air which had been combined with the water, and which by change of temperature have been evolved from it and fixed by attraction on the glass. This is still more strikingly observed when the glass of water is submitted to a diminution of pressure in the receiver of an air-pump. Any solid introduced into the water, such as a sheet of tin plate, will equally attract them.

Water has always more or less air mixed up with it and kept in it by adhesion; and it may be seen in the form of fine bubbles within the ice when the water is rapidly frozen. The water of certain deep lakes in colder countries than England, such as Canada, is frozen more gradually, and the air thus has time to escape. The ice thus obtained is as pellucid as the diamond, and quite free from air.

The difficulty of getting the air out of the pores in a solid is owing to adhesion. Thus, if we sink a cork in water it does not get thoroughly soaked for some time; gradually the water presses the air out, and by-and-by it appears clinging to the surface in small silvery beads. The air contained in the pores of a lump of sugar is seen shooting up from the surface after we drop it into a cup of hot tea. So it is due to this that it is next to impossible to get the air out of the minute cells of the lungs after it has been once introduced by breathing.

"*Solution.*"

81. When a solid is dissolved in a liquid—as sugar or salt in water, sealing-wax in spirit of wine, gold in mercury—it is simply the power of adhesion overcoming the power of cohesion in the solid; and the limit to solution or the saturation point, when the liquid refuses to dissolve more of the solid, is when the attraction of adhesion just balances that of cohesion.

Whatever diminishes the cohesion increases the degree or power of solution; thus alum reduced to powder dissolves much more readily than in a single lump; and heat, because it increases the distances of the molecules and reduces the cohesion, favours solution proportionately.

No doubt there are exceptions to this last rule, for there are some cases where the solvent power of a liquid is reduced by heating, as, for example, lime in water; if we make a saturated solution of lime in ice-cold water, it will deposit one half of the lime when we raise the water to the boiling point. Another illustration of the same kind is seen in the solution of Glauber's salts; ice-cold water will hold about one-tenth of its weight of these salts in solution, but, as the water is heated up to boiling, hard gritty crystals are deposited to the extent of one-fifth of the original quantity dissolved.

The reason of this appears, however, to be that heat diminishes at once the adhesive and the cohesive attractions; and the latter being in most cases the more delicate or smaller in range is, so to speak, soon out of the field in comparison with the adhesive; but in these exceptional cases the adhesion diminishes more rapldiy than the cohesion with increase of heat, and hence the anomalous results.

In *solution* a certain resemblance in the nature of the bodies adhering is necessary; thus, mercury dissolves the metals; oils dissolve fats; and alcohol resinous substances. And this is very important, because, along with the fact that the solution retains the properties of both the solid and the liquid, it serves to distinguish between this molecular adhesion and chemical attraction, which, as we shall consider presently, is strongest between particles of unlike nature.

"*Adhesion between liquids.*"

82. When one liquid mixes with another, it is a case of solution and similar in character to the former; the mutual adhesion overcomes the individual cohesion; and when the different attractions balance each other the two are mutually saturated.

A drop of vitriol may be mixed with a pint or a quart of water with equal readiness, and every drop of the mixture will taste acid, showing that the adhesion of the water and vitriol is so great as to overcome the cohesion of the latter to any degree of minuteness.

On the other hand what chemists call the essential oils are but slightly soluble in water; if we shake, say oil of peppermint with water, only a very small quantity of the oil will adhere to and permeate the water, and the two will separate again almost entirely, the adhesion not being sufficient to overcome the individual cohesions.

A very interesting illustration of this contest between adhesion and cohesion is seen when we let fall on the surface of water a drop of any oil which is but sparingly soluble in it. Naphtha, paraffin, creasote, or turpentine may be used to show the effect. Adhesion tends to draw the drop to the liquid so as to mix thoroughly, and its cohesion tends to prevent this; so that the extent to which the drop will spread, and its behaviour in the act will depend on the mutual relations of the two attractions, and will consequently vary for every substance. Thus each oil has its own *cohesion figure*, as it is termed, and may be distinguished by this from all others; an important fact to the chemist, enabling him to detect differences and mixtures of oils with great readiness.

83. Under the power of cohesion alone, any mass of liquid assumes the spherical form, as is seen in the case of rain-drops in the air; or more beautifully and permanently with a little oil dropped gently into a mixture of alcohol and water of about the same density

But if the cohesive attraction be interfered with, as by adhesion, for instance, the form is no longer spherical ; as we see in the shape of a drop on a window-pane or of a soap-bubble before it is detached from the pipe by which it is blown.

Of course in large masses of liquid, cohesion ceases to influence the shape, being quite overpowered by the earth's attraction, which, tending to draw all the particles as near its centre as possible, makes the surface what we called level ; that is, everywhere at the same distance from the earth's centre.

"*Capillary attraction.*"

84. The adhesion of solids and liquids is well exhibited in an important class of phenomena, where it is usually designated by the special name of *capillary attraction.*

When a plate of glass is dipped in water, the liquid clings to the glass, and is consequently raised up to a small height above the surrounding level.

If we dip two plates, and bring their faces very near together, we shall see the water creep up between the plates—to a greater or less height according as they are more or less approached. There will also be a slight drawing together of the plates by the cohesive action of the liquid between ; just as, when a gymnast raises himself up between two ropes by grasping one in each hand, there is an inclination of the ropes at the lower end. This effect of adhesion, in raising liquids between near surfaces of solids, can be best seen and studied by using glass-tubes of various degrees of fineness, because in these we have the surfaces approached on all sides round about. *Capillary* is the name usually given to this attraction from its having been first noticed in small glass tubes scarcely larger than hairs (*capillus*, a hair).

85. If one end of an open glass tube of fine bore is dipped in water, the liquid will rise up to a considerable height above its level, and higher and higher as we use finer bores. A bore of one half the width of another will raise the liquid to twice the height. With the same tube water will be drawn up fully twice as high as spirit of wine, because the cohesive force of the former is much greater than that of the latter.

But a difference in the material of the tube has no effect on the height provided only the liquid can wet the tube. A tube of wood and one of glass will raise water to the same height if they have the same size of bore.

86. The following examples illustrate the operation of this principle :—

Water, ink, or oil coming in contact with the edges of a book is rapidly absorbed far inwards among the leaves.

A piece of sponge or a lump of sugar touching water by its lowest corner soon becomes moistened throughout. A heap of sand on a wet surface becomes speedily wet to the summit.

The walls of the upper rooms of houses built on a damp soil are often rendered damp by the moisture traversing by capillary attraction the porous bricks from the foundation upwards.

The wick of a lamp lifts the oil to supply the flame from two or three inches below it.

Ink passes to the point of a pen between the two edges of the slit.

A mass of cotton thread hanging over the edge of a glass from the water within it will empty it drop by drop. The corner of a towel dipping into a basin of water will empty it in the same way.

Dry wedges of wood driven into a groove formed round a pillar of stone near one end will, on being moistened, swell with sufficient force to rive off the portion from the block. In some French quarries, millstones are thus cut from the rock.

A great weight suspended by a dry rope may be raised a little way by merely wetting the rope ; the moisture imbibed by capillary attraction causes the rope to swell laterally, and so to get shorter.

87. Capillary attraction plays a most important part in the world of animal and vegetable life, on the one hand influencing the fluid circulation and the passage of the various secretions through the porous tissues of all organized beings ; and on the other, conveying the life-giving moisture through the soil to the roots of vegetation. We cannot indeed say that it is the sole cause in maintaining the circulation of the sap in living plants, for the evaporation, &c., constantly going on through the leaves and skin is most probably, like the breathing of animals, the real source of *activity*, and capillarity in itself would be incapable of producing a continuous flow.

" *Capillary depression.*"

88. When a tube of small bore is dipped in a liquid incapable of wetting it, as a glass tube in mercury, or an oiled glass tube in water, there is a lowering of the level of the liquid within the tube, its surface being convex or rounded in place of concave or hollow, as in the former case. The same is seen if we dip a rod or slip of glass in mercury, there is a rounding of the liquid edge next the glass and a depression as if it were repelled by it. This is of course not the case. The explanation is simply that the adhesion to the glass is too weak to affect the shape which the cohesion imposes on the mercury.

It has been calculated that, as a general rule, if the adhesion of the liquid and solid be greater than half the cohesion of the liquid, the solid will be wetted by it, and the liquid will rise in a tube of this substance ; but if less than one half, the liquid cannot wet the solid, and there will be a depression of the liquid within a fine tube.

89. Certain modifications or peculiar manifestations of adhesion and capillarity exhibited in *absorption*, *exhalation*, *imbibition*, *osmose*, and *diffusion of liquids and gases*, will be dealt with when we have considered the properties of liquids and gases.

90. So much for the varied manifestations of molecular attraction. They come within the experience of every-day life, and are of the utmost importance in the multitude of human avocations.

But we have not yet done with attraction. When we pass to the confines of material existence we can still trace the operation of a similar principle, by which the ultimate parts of substance spontaneously group themselves in endless variety. This interatomic attraction is the living power of the material universe, and is the final source to which it is possible to trace any change in the world about us.

"*Interatomic or Chemical attraction.*"

91. There are some points of resemblance between interatomic or chemical attraction and the forms of attraction already considered ; the points of difference, however, are much more decided.

In the first place, the chemical affinity (as it is usually, though not quite correctly, designated) between atoms does not appear in any way to correspond to their gravity, but exhibits the most singular and unexpected variations of degree.

Secondly, it differs widely from cohesion or adhesion, inasmuch as these are more powerful between similar than between altogether dissimilar kinds of matter, while chemical attraction is stronger the more unlike the natures of the atoms. Between some atoms there seems to be absolutely no attraction at all, between others it is so violent that they appear eager to rush together.

Thus, sulphuric acid will not unite with gold, but it will very readily combine with iron or copper.

An acid of one kind does not combine chemically with an acid of another kind, but it will unite instantly with an alkali.

In all these cases of chemical union the properties of the compound are different from those of its constituents, while in a mechanical mixture each constituent retains its properties, so that they may be entirely separated from each other by mechanical processes. In a chemical compound such a separation cannot take place except by the exercise of chemical attraction in another form.

As an illustration, gunpowder is a mixture of nitre, sulphur, and charcoal. The nitre may be separated from it by solution in water, the sulphur by solution in benzole, and the charcoal remains. In spite of mixture each substance retains its special properties. When a heat of 540° is applied to the mixture, the three constituents are resolved into various chemical compounds of gases and vapours. The elements are the same, and the weight of the products is equal to the weight of the gunpowder; but the properties of these substances are entirely changed. The nitre, sulphur, and charcoal no longer exist as such in the products.

92. *The distinguishing feature of chemical attraction is, therefore, that it destroys, or at least masks, the individuality of the atoms or molecules united.*

This draws the line between adhesion and chemical attraction. When sugar is dissolved in water, every drop has at once the properties of water and of sweetness combined; the one is not lost or merged in the other, because the union is merely collateral; it is not one of fusion. If, again, we mix sand with powdered soda they may lie side by side unchanged for centuries; but the chemical union of the two produced by melting them under a strong heat turns them into transparent glass, a substance altogether different from either of the constituents.

Sulphuric acid unites with copper, and produces a beautiful transparent blue salt (commonly known as blue vitriol). By heating this blue salt to a moderate temperature it becomes perfectly white, and on adding to it colourless water it becomes again blue. Thus colour is imparted under chemical attraction by combining two colourless substances.

93. It is impossible to predict the effect of the chemical union of any two elements, although we may know all about them individually. Often the result is most surprising. Thus, the study of atomic actions is wholly an EXPERIMENTAL one.

Hence it follows that the properties of a chemical compound cannot be inferred from the properties of its constituents. Its physical condition, whether as a gas, liquid, or solid, and its chemical and physiological characters can be determined only by experiment.

Nitrogen and hydrogen are two comparatively inert gases, while carbon is an innoxious black solid. The combination of these three bodies produces a highly poisonous liquid—prussic acid. Hydrogen has no smell, and sulphur only a slight smell if rubbed; when chemically combined, these substances produce a most offensive-smelling gas—the sulphide of hydrogen. Carbon, hydrogen, oxygen, and nitrogen are innoxious agents, and have no taste. When chemically combined in certain proportions they produce strychnia, remarkable for its intensely bitter taste and highly poisonous properties. Iron manifests magnetism most powerfully, and oxygen is the most magnetic of gases, yet these two bodies, when chemically united in the proportions of two of iron to three of oxygen, produce a compound in which no trace of magnetism can be discovered.

It is to be remarked that this change of properties is only temporary; when the chemical union is destroyed the bodies resume their original properties, and magnetic iron and oxygen may be re-obtained from the non-magnetic compound iron-pyrites.

Sugar is an innocent substance. By dissolving it in nitric acid of a certain strength it is not recovered as sugar, but re-appears in the form of crystalline prisms of that powerful poison, oxalic acid.

The constituents of gunpowder are not explosive or in any way dangerous if kept apart. When the nitre, sulphur, and charcoal are mixed in certain proportions and well incorporated in the state of the finest powder, they form, by the application of heat, a dangerously explosive substance; each solid cubic inch of gunpowder being suddenly converted into 2000 cubic inches of gaseous matter.

Glycerine is a perfectly innocent syrupy liquid obtained in the manufacture of soap. It has no explosive properties. When dropped into a mixture of nitric and sulphuric acids, it combines with some of the elements of the former and produces a brownishcoloured liquid—nitro-glycerine, which explodes by concussion so violently as to destroy everything in contact with or near it.

So with all the other physical or chemical properties of compounds; they must be ascertained by actual trial, they can never be determined from a knowledge of the elements.

Sugar is but a union in certain proportions of pure carbon (or charcoal) with the elements of water.

Sulphur and quicksilver, when heated together, form the beautiful red pigment known as vermilion.

Sulphur and iron, combined at some remote period, have produced those gold-like cubes called iron pyrites which are seen in slates.

Lead, with oxygen absorbed from the air or other source, forms the red lead used by painters.

94. One most important exception there is to the statement that the effects of the action of unknown elementary substances are incalculable, and it is this:

Atomic actions in no way interfere with the weights of the elements: the weight of any compound is just the sum of the weights of its constituent particles.

Unnecessary and self-evident as this statement may appear, it was long after the dawn of philosophy ere its true import was recognised, and now it may be said that on this simple hypothesis is built the whole structure of modern chemistry.

It is from this that the chemist infers the indestructibility of matter itself, and it is from this that he infers the independent existence of sixty-five different elementary substances.

Provided with an extremely delicate balance or means of detecting changes of weight, the chemist causes different chemical agents to react on each other within a vessel or envelope, which is unaltered by his operations, or he causes matter to be dissipated into vapour and pass from view altogether, and finding not the smallest change of weight to follow, he concludes that the *quantity of matter* is unchanged, and unchangeable by any kind of chemical action.

So, again, assuming that an *increase of weight always indicates an addition of matter, and a loss of weight always a withdrawal of matter*, he concludes that iron, gold, oxygen, and hydrogen, are elementary substances. For by no process of heating or chemical action can he separate an ounce of iron, say, into two quite different substances whose weights shall be together an ounce; and when an apparent decomposition takes place, as in the rusting of iron, he finds on weighing that, the mass is heavier than before, and concludes that the rust is really a more complex and not a more simple substance than iron itself.

95. The most striking feature of chemical combination is that the union cannot be made, as in mechanical mixtures and solutions, to take place in any proportions. We may dissolve a small piece of sugar in a cup of tea, or we may dissolve several large lumps. The only difference will be that each drop in the latter case will be much sweeter. Ultimately we may have a limit, when a drop refuses to become more sweet, that is to say, when the adhesion between the liquid and the sugar just balances the cohesion of the latter.

In real chemical combinations, however, the limits are quite definite. Thus, if we mix three measures of hydrogen with one of oxygen, and apply a light, we find that all the oxygen disappears, but that an unemployed measure of hydrogen remains. The two will combine to form water vapour in no other proportion than that of two of hydrogen to one of oxygen, whatever quantities of each there may be.

So the proportion of elements in any compound is always the same: it owes all its qualities, its very existence, to the union of the elements in certain special proportions. There is no accidental or indifferent mixture, with a corresponding gradation of properties.

96. Sometimes, indeed, two elements will combine in different ways under different circumstances; but the transition of proportions and of physical properties is always abrupt and at the same time perfectly definite.

As a general rule, when two elements may unite in several ways, they invariably follow definite proportions. A single measure of the one combines with one, two or more of the other, or two measures of the first combine with one, three, or five of the second, and so on. We never have a complicated numerical relation between the combining measures.

97. Further, there is an equal simplicity of relationship between the measures in which two elements combine, and those in which each of them combines with a third. Two measures of hydrogen, as we have seen, go with one of oxygen to form water; now, if we try how these unite with a third element, say carbon, or sulphur, we find that a measure of carbon unites either with two of oxygen, or with four of hydrogen, producing in the former case carbonic acid gas, and in the latter marsh gas (so called because it is copiously produced by decomposing vegetable matter in boggy or marshy places); or again, one of oxygen unites with one of carbon, to form carbonic oxide gas, or two of carbon unite with four of hydrogen, producing olefiant gas.

98. All this proportionality and definiteness seems to point to some ultimate definiteness of character in matter, of which this is only the outcome. Such is the atomic theory or hypothesis, which asserts that there are ultimate particles or atoms, unchangeable by any known force, which have an individuality of size, weight, and chemical power for each simple substance, and that the union between two elementary bodies is one among the atoms, whereby they group themselves in pairs, triplets, &c., according to circumstances. Assuming this, we have at once a clear conception of the cause to which the facts above mentioned are due; without this assumption we are left in mist and mystery.

99. Atomic attraction plays in the universe a most important and most potent part, its energy being as intense as its sphere of action is limited.

How very soon will a few drops of acid destroy the tenacity of an iron wire, which a weight of perhaps a ton could not tear in pieces!

What an irresistible (heating) power is called into action by the union of oxygen and hydrogen, as is seen in the oxy-hydrogen blowpipe, which will burn or break up the most intractable substances!

The electric pulse that beats through the 2000 miles of Atlantic cable between the old world and the new, is but another manifestation of this power. Heat is, doubtless, the direct product of atomic attraction; but heat is power. Whence comes the moving power of our coal fields, our engines, and our factories, but directly or indirectly from this atomic attraction? To this we owe all combustion and heat on our globe which does not come to us through space from the sun.

100. Attraction, then, pervades creation from centre to circumference.

As gravitation, it is the muscle and tendon of the universe by which its mass is held together, and its huge limbs are wielded:

As cohesion and adhesion, it determines the multitude of physical features of its different parts:

As interatomic action, it is the final source to which we trace all material changes.

Some would attempt to ascribe the three varieties of attraction to one common origin, or to reduce them to different forms of the same force, as there are some who would have the different kinds of substances to be but variations of one fundamental material. But these generalisations are yet far from being established.

SECTION II.—THE PHENOMENA OR MOTIONS OF THE UNIVERSE.

ANALYSIS OF THE SECTION.

The material universe from its minutest to its grandest masses is in ceaseless motion, and to the intelligent study of its phenomena, the investigation of the general laws of motion is a fitting preliminary.

VELOCITY *is the rate of motion, and this may be, first,* UNIFORM, *as that of the earth round its own axis, which is therefore taken as our standard of* TIME, *the co-existence of an event with a whole or a twenty-fourth part of a turn of the earth being denominated a duration of a day or of an hour Most commonly, however, we find velocity* VARIABLE, *and either* (1) ACCELERATED, *i.e. gradually increasing, as in the case of falling stones, water, &c., or* (2) RETARDED, *i.e. gradually diminishing, as in the case of bodies thrown upwards, and in the case of all artificial motions which, owing to the effect of friction, tend sooner or later to cease, the grand impossibility being a perpetual motion.*

Several motions may exist simultaneously in the same body, as, when a stone is thrown obliquely, it has a horizontal and at the same time a downward motion, owing to the attraction or pulling of the earth. The resulting or resultant *motion is found in such a case by the rule known as the* PARALLELOGRAM OF VELOCITIES ; *and the resultant of several simultaneous motions by a simple extension of this rule.*

But matter in motion is FORCE, *and the measure of force is the* MOMENTUM *or quantity of motion, which depends on the quantity of matter moved and on the velocity conjointly. Thus a force acting on a body being equivalent to a definite motion of the body, the composition and resolution of forces are identical with the composition and resolution of velocities. Forces, as velocities, may be* uniform, accelerated, *or* retarded ; *the most important example of accelerating force being* gravity, *or the attraction of the earth ; the uniformity of this acceleration, which is the same for all bodies, light as well as heavy, being very clearly shown by means of Attwood's machine.*

A comprehensive summary of the laws of force or moving matter is given in NEWTON'S LAWS OF MOTION ; *the first of which—viz. that a body free from external influence cannot of itself change its state either of rest or of motion—corresponds to the law popularly known as the Law of* INERTIA : *the second justifies or is the foundation of the rule given as the* PARALLELOGRAM OF FORCES, *and is to the effect that the direction and amount of change of motion is a measure of the external force or influence acting on a body.*

The third, which is commonly quoted in the words, "action and reaction are equal and opposite," *corresponds to the modern doctrine of* ENERGY, *which asserts that the creation of force, energy, or moving power is not to be found in nature, and that every motion is but the result, outcome, or transformation of an equivalent amount of energy already existing in some form or other: all the various forms of energy in the universe being mutually connected and interchangeable according to definite though but partially discovered laws, a fact which is usually referred to under the name of the* CONSERVATION OF ENERGY OR FORCE.

"*Motion and force.*"

101. *Motion* is the changing of place among bodies, their positions being compared with each other or with some fixed position. *Force* is whatever produces or is capable of producing any kind of material change.

These three phenomena—matter, motion, force—are constantly associated in our experience, so that we do not know of the existence of either apart from the others.

Motion is everywhere. The rising and the setting sun—the rolling river—the moving winds—all animal existence—the quiver of the air that we call sound—the rays of heat and light that in very truth beat upon our earth—exemplify its universal reign.

To trace the relations of these various motions and changes, and to assign them, where possible, to a common origin is of prime importance, as it enables us, to a great extent, to foretell the future and to adapt our actions accordingly.

"*Motion.*"

102. Motion may be *swift,* as that of the lightning; *slow,* as that of the sun-dial shadow; *straight* (or *rectilinear*), as that of a body dropped from a height; *bent* (or *curvilinear*), as that of a body thrown obliquely; *regular* (or *uniform*), as that of the hands of a clock; *irregular* (or *variable*), as the motions of the wind, of animals, and as most familiar motions; *accelerated* (or gradually increasing), as the motion of a falling stone; *retarded* (or gradually diminishing), as in the case of a stone thrown up, and in the case of most visible motions.

103. *Velocity* is the term used to denote merely the *rate of motion,* no matter how fast or slow. We measure or estimate it by the space passed over in any time—such as an hour, or a minute, or a second, according to the degree of nicety we wish to express. Only we suppose that during this time the velocity remains unchanged.

A flash of lightning or a meteor may dart across the sky, and may last but a small part of a second. When we say that it had a velocity of a thousand miles a minute, we simply mean that had it travelled at the same rate for one complete minute it would have passed over a thousand miles.

A passenger in a railway carriage, saying that the train is now at thirty miles an hour, understands not that he will actually travel thirty miles during the next hour, but that he would do so were the speed to continue what it is for an hour. Probably the speed is at no two successive moments precisely the same; it has gradually increased from rest to its present rate, and it may gradually get less and less till reduced to zero again at the next station.

104. A motion is fast or slow only by comparison with some common or well known velocity, such, for example, as any of the following (the unit of time being *an hour*, and of distance *a mile*) :—

Man walking	from	3 to 4	miles per hour.
Man on a bicycle	„	12 to 16	„
Horse trotting	„	7	„
Horse galloping	„	20 to 40	„
Railway train	„	25 to 50	„
River current	„	3 to 4	„
Gentle wind	„	7	„
Hurricane	„	90	„

If the unit of time is taken at a single *second*, then we have the means of comparing a large number of velocities of various kinds, premising that the spaces traversed by light and electricity are indicated in miles in place of feet.

	Miles in one second.
Light	192,500
Electricity not less than.	200,000
Electric currents in telegraph wires	12,000*

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* It would thus require only two seconds to traverse the whole circumference of the earth at the Equator.

	Feet in one second
Relative motion of the sun in space	205,920
Aërolites or shooting stars	114,000
Mean rate of the earth's centre in its orbit round the sun	101,061
Sound traversing solid bodies	11,280
Mean velocity of air from explosion of gunpowder	5,000
Sound traversing water	4,480
Volcanic stones projected from the volcano of Teneriffe, 1798	3,000
A 24-pound cannon ball (maximum)	2,450
Rifle ball (maximum)	1,600
A point at the surface of the earth under the equator	1,525
A common musket ball	1,280
Air rushing into a vacuum	1,280
Volcanic stones projected from Etna	1,250
Sound traversing air at a temperature of 60°	1,120
Sound traversing air at 32°	1,089
A point at the earth's surface, latitude of London	950
Bullet discharged from air gun (pressure equal to 1500 pounds on the square inch)	697
Maximum velocity of wave of Lisbon earthquake, 1755	642
Flight of a swift	252
Minimum velocity of wave of Lisbon earthquake, 1755	184
The most violent hurricane	146
Flight of a swallow	134
Flight of an eider duck	132
Waves in a heavy swell of the open South Atlantic Ocean	130
A hurricane	117
Locomotive on the North Western Railway (70 miles per hour)	102
Locomotive on the Great Western Railway (65 miles per hour)	95
Flight of a falcon	83
The swiftest race horse	80
A storm (also a tidal wave in the British Channel)	73
An ordinary race horse	42

	Feet in one second.
Flight of a crow	37
A brisk wind	36
Man on a bicycle	24
The fastest sailing vessel	15
Current of the most rapid rivers	13
A wind of mean intensity	10
A carriage going six miles an hour (nearly)	9
Man walking	6
The gulf stream maximum	7
An ordinary wind	6
Mean velocity of the current of rivers	4

Some of these velocities have been given by Peschel; others are based on calculations derived from reliable observations.

"*Uniform motion or velocity.*"

105. A body has a uniform motion or velocity when it passes over the same distance in each second or minute of its duration; and we get the same idea of the rate, whether we consider the space traversed in a long or in a short time.

Our standard of uniform motion, with which we compare and measure all other motions, is that of the earth round its own axis. Here we have a huge spinning-top, which, not for hours or days, but for unknown ages, has kept up its original speed practically undiminished. All our notions of *time* are based on the regularity with which the earth turns round. We can tell, roughly, by looking at the position of the sun, and more accurately by noting the position of any star, when our earth has made a complete revolution. Any phenomenon lasting while the earth makes one or ten of its revolutions, is said to have a duration of one or ten days; and if it last while the earth makes one twenty-fourth part of a turn, it is said to be of an hour's duration.

It would be rather difficult to tell from the sun or stars when the earth has made a twenty-fourth or forty-eighth part of a turn; but various inventions have been made which enable us to say with very great nicety what fraction of a day or revolution of the earth has passed. Watches and chronometers are but contrivances for producing a practically uniform motion which can be readily compared with that of the earth, but whose subdivisions can be more easily referred to and noted than the latter. And to such perfection has this artificial uniformity attained, that modern astronomical clocks and chronometers are constructed which scarcely vary a single second in the course of a whole year.

In point of fact, the motion of the minute hand of a watch is not uniform, but consists of a succession of little hops, which may be seen when we look at the seconds hand, but which are no more considered than the steps of a horse when we speak of riding at a uniform rate.

In the more antiquated contrivances for measuring time, such as the sand-glass, and the water-dropping clepsydra, or in the flow of mercury through a small opening in the bottom of a funnel, which is used even at the present day, we have a motion that is really continuous and free from interruptions, though it may not be so generally convenient for measuring as that of a clock.

" *Variable motion.*"

106. When the motion of a body is not uniform, as in the case of a body falling to the earth, it is obvious that we shall have a truer idea of the rate at any instant the shorter the interval of time through which we can measure the space passed over.

The captain of a steamboat may form a very incorrect idea of the actual speed of his vessel if he merely know the distance passed within the last two hours ; he comes much nearer the actual speed if he know the distance traversed within the last minute ; still nearer if he can tell how far he has gone during the last second, or tenth or hundreth of a second.

> In other words, the *exact* velocity of the steamboat at any instant may be quite a different thing from its *average* velocity for the past hour or two hours.

If the velocity be a rapidly changing one, our power of noting time must be correspondingly nice if we wish to measure the velocity at any moment. Thus, the explosion of gunpowder within a cannon gives motion to the bullet gradually, yet so rapidly, that the whole time occupied in its passage through the cannon is inappreciable by ordinary means of time measurement. But, in recent years, an electric chronoscope (or time-detector) has been invented that indicates the very small fraction of a second taken by the ball to pass from point to point within the cannon ; and so the law of the rate according to which the motion is imparted can be ascertained—a point of great importance in gunnery.

Of the cases of variable motion the most important are those where the change is uniform or regular, because only then is the motion calculable.

" *Uniformly accelerated or retarded motion.*"

107. If, by accident, a carriage gets detached from a train which is standing on an incline, it will move down the incline with a constantly increasing speed. At the end of the first second the velocity would not be great, and there would be little difficulty in stopping the runaway carriage. In three seconds its speed will be triple what it was at the end of the first second ; at the end of a minute it will be sixty times as great, and may defy the power of the brake to arrest its impetuosity.

A stone allowed to drop from a height to the earth will have a velocity of about thirty-two feet at the end of the first second, of sixty-four feet at the end of the next second, of one hundred and sixty feet at the end of the fifth second of its fall, and so on.

These are examples of uniformly increasing (or accelerated) motion, because the velocity is constantly increasing by the same amount.

108. Uniformly retarded motion is seen when we shoot an arrow vertically up. Its speed gets less and less by the same amount during each second of its flight, till at last it is brought to rest, and the operation begins to be reversed.

The application of the brake to a train may reduce its speed from thirty miles an hour to twenty-eight, twenty-six, or twenty-four miles an hour in one, two, or three seconds, in which case the effect of the brake is a uniform retardation of the motion.

109. Nearly all motions that we meet with in nature are accelerated or retarded. The production of motion, as will be more fully considered afterwards, is never absolutely instantaneous, but always more or less gradual ; the stoppage of motion takes place also by degrees, though the time occupied may not always be appreciable.

The acceleration or retardation of motion is not, however, in every case, or even in many cases, uniform. For example, the velocity of a rifle ball at the end of the first half-second after the explosion will be much more than double of what it was at the end of the first quarter of a second.

" *Absolute and relative motion.*"

110. A man sitting on the deck of a sailing ship has common motion with the ship, though *relatively* at rest as regards it ; if walking on deck, he has one motion relatively to the vessel, and another relatively to the land. If he walk towards the stern just as fast as the ship sails, he is at rest relatively to the sea-bottom or shore.

A boat rowed against the stream as fast as it flows is at rest as regards the river and the earth just as much as if it were moored.

Absolute motion would be change of position compared with some absolutely fixed point of reference. In reality we cannot know such motion, because there is no spot in the universe absolutely at rest, so far as we can tell. All nature is in ceaseless movement, and thus every motion is only relative to some other moving body. When the term absolute is used, therefore, it must be understood as taken in a limited sense, the motion of the point or place of reference not being considered as affecting the conditions of motion.

Thus, in comparing the motions of the hour and minute hands of a watch, we may say that their real or absolute motions are five minutes and sixty minutes respectively per hour, but that the relative motion of the minute hand compared with the hour hand is fifty-five minutes per hour.

"*Co-existence of motions.*"

111. A body may partake of two or more motions at the same time.

Our earth keeps turning once a day round itself, and at the same time wheeling round the sun at the rate of once a year; in all probability it is also moving with the sun and its sister planets round some other greater central sun.

A top set spinning on a plate of glass will rotate and at the same time travel over the glass.

Smoke ascending from a chimney, or a balloon rising from the ground, is at the same time driven away in a cross direction by the wind.

112. When a body possesses two simultaneous motions, either in the same or in different directions, it is often of much consequence to know the conjoint effect of the motions, or the actual movement relatively to some object independent of both.

"*Simultaneous motions in the same direction.*"

113. If a person walk towards the prow or the stern of a steamer in motion, he has at the same instant two velocities; and the actual rate of his motion, referred to the land or an object independent of both motions, is the sum or difference of his velocity and that of the steamer, according as he walks towards the prow or the stern.

A clown leaping forward when his horse is at full speed, will light on the neck of the horse just as he would if it were standing still, because, by leaping, he simply adds motion to the motion which he already has.

"*Co-existing motions in different directions.*"

11. A ferry-boat rowed straight across a river may at the same time be borne by the current as fast down the stream; and the resulting motion will be neither right across nor down the stream, but in an intermediate direction.

If the velocity down the stream be three times as great as that across the stream, the direction of the real or ***resultant*** motion will be more inclined to the bank of the stream than to the line right across, and may be found in the way shown by fig. 2 :—

Take a line, A B, to represent the direction of the flow of the stream three times the length of a line, A D, in the direction of the breadth of the river, and complete the parallelogram by drawing lines D C and B C parallel to A B and A D.

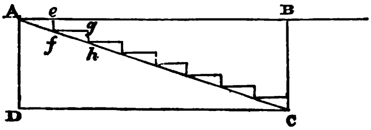

Fig. 2.

Then A C will show the direction in which the boat will actually go. For while it is borne a distance, A *e*, during any instant, it is rowed one-third as far across in the direction of A D, so that at the end of that instant it will be at *f*; during the next similar instant it will be carried a distance, *f g*, in the one direction, and one-third of that, *g h*, across that direction, being at *h* at the end of the second instant. Thus, at the end of every such instant the boat will be in the line A C; and this is true for the smallest conceivable instant. Hence, we see that the boat will not be out of the line A C for the smallest conceivable instant. In other words, the true course of the boat will be seen to be along A C.

115. Nor is it necessary that the one motion be right across the other.

A ship sailing in the direction A B (fig. 3), may at the same time be drifted by the tide in the direction A D. At the end of successive seconds or instants it will have gone for the distances A *e*, *f g*, &c.,

in the one direction, corresponding distances, *e f*, *g h*, &c., in the other; so that its course will clearly be along the diagonal or middle line of the parallelogram, A B C D, whose sides, A B and A D, represent the directions and rates of the simultaneous motions.

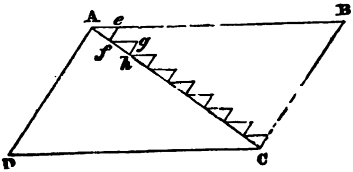

Fig. 3.

If the velocities in the two crossing directions be equal, then the resulting motion must be exactly midway between these directions; for there is no reason why it should be nearer to the one than the other.

Thus a boat's motion is the resultant of equal velocities communicated by the oars on each side.

This explains also why a bird flying, or a man swimming, holds a perfectly straight course.

116. In ascending a staircase or the side of a hill we execute the resultant of a combined vertical and horizontal motion. We have an unlimited command of horizontal, but only a very limited command of continued vertical movement. Yet, by combining the two, we produce a continued resultant motion, and so obtain a continued vertical one also.

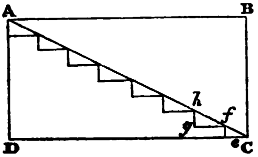

Fig. 4.

This simple rule for finding the actual motion, or *resultant*, as it is termed, of two co-existing motions is known as the *Parallelogram of motions or velocities*. It is of the utmost importance, both in theory and practice.

117. On the same principle we find the conjoint effect of three or more velocities which a body may possess simultaneously.

A train may possess a *north*, an *east*, and a *vertically upward* motion at the same instant. If we take O B and O C to represent the north and east motions of the train, and O A to represent the vertical one, or the rate at which it is rising perpendicularly; then, completing the solid figure, A B C D, by drawing parallels through A, B, and C, we shall have the resultant motion represented in amount and in direction by O D.

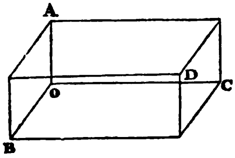

Fig. 5.

In other words, if a body were urged simultaneously to move in each of the directions O A, O B, O C, at rates represented by those lines, then it would actually move along O D at a rate represented on the same scale by the length of O D.

"Resolution of motion or velocity."

118. We are but stating the same principle from the other side when we say that any motion or velocity may be regarded as equivalent to a compound motion taking place in two or more directions at once.

A meteor moving in a slanting direction from the north-east to the earth may be supposed to have three co-existing velocities—one from north to south, another from east to west, and a third vertically down.

When we consider the motion as thus broken up into three co-existing motions we are said to *resolve* it into its *components in any given directions.*

In cases of rectilinear motion the value of this mode of regarding it is not so apparent; but when we have to deal with curved motion, as with that of a stone thrown obliquely, it becomes absolutely necessary to our calculation of the rate and direction of motion at any time that we consider the body as possessing at once two distinct velocities, each independent of the other.

119. The proportion of motion that goes to each direction is obtained very readily by the rule of the parellelogram of velocities.

Thus, a train moving in the direction A C at the rate of six miles an hour is approaching a point, P, in one direction at a certain rate, and at the same time approaching a point, Q, in another direction at a certain rate.

These rates may be found in this way :—

We take a line, A C, to represent the actual motion, and draw parallels through C to the directions in which P and Q lie from the starting point of the train. We thus form a representative parallelogram, A B C D ; so that if A C measure six inches, while A B is four, and A D three inches, the train will be approaching P at the rate of four, and Q at the rate of three miles an hour.

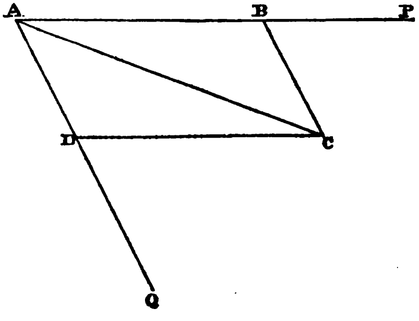

Fig. 6.

"*Parabolic path of a projectile.*"

120. The resultant of two or more velocities is straight when the velocity in each direction keeps unchanged; but if the rates of motion do not remain the same comparatively, then the actual motion will be curved.

A ferry-boat rowed at a uniform rate across a river, and borne at a uniform rate down by its flow, will describe an intermediate rectilinear path.

On the other hand, a bullet shot obliquely from a rifle, say in the direction represented by A K, possesses simultaneously, first, a sensibly uniform velocity, due to the explosion in the direction A K, and, second, a constantly increasing velocity in the vertical direction, due to the pulling of the earth. The result is a curved motion of the bullet along A D F B. During the time it would have gone from A to C in virtue of the velocity imparted by the shot, it will have fallen towards the earth by an amount, C D; and during the time when it would have gone twice as far—from A to E—in virtue of this original motion, it will have fallen through a distance, E F, not twice, but *four* times as great as C D, and the downward velocity at F will be twice what it was at D. Thus, the route taken by the rifle-ball is not straight, but curved, and this is the explanation of the well-known curved course always taken by a stone thrown, an arrow shot, or a fountain playing obliquely.

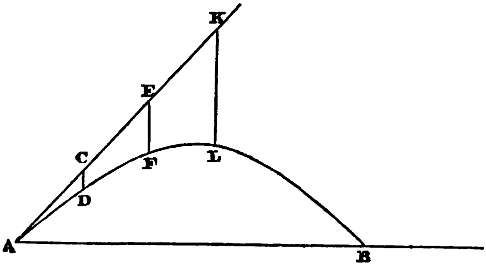

Fig. 7.

A jet of water, or the fiery trail of a rocket, exhibits to the eye the *parabola* or curve described by a body thus projected.

121. It is, in every case, this parabolic course which a body will pursue if it be subject to a uniformly increasing velocity in one direction and a constant one in another. But, with a different relation between the component velocities in any two directions, a different curvature of actual path will obtain.

122. We might keep the idea of matter in abeyance, and pursue this study of motion in the abstract much farther. It is of great importance in all branches of natural philosophy, as well as in those practical sciences—such as gunnery, mechanism, &c.—where motion is the most prominent feature; just as the abstract study of the rules of arithmetic is of the utmost consequence for the business and trades of practical life, where they have incessant application.

But for the nature of this work the further development of these abstract principles is unsuitable, and we accordingly proceed to consider motion as we find it expressed in nature, namely, rolled up in matter, the two together forming what may be called the *factors of force.*

"*Force.*"

123. A rifle bullet in motion possesses force; when at rest, it is powerless.

If the hand be laid on the table, and a weight be placed on it, it presses with a certain *force*, which is simply the pull that the earth exerts on the weight. A magnet draws a piece of iron, or the earth draws a magnetic needle into a north and south direction with a certain *force*, which we can measure. Iron wire resists being pulled asunder with very great *force.*

> In these and in all other instances, the idea conveyed by the word *force* is a ***tendency to put matter in motion***, whether the effect of that tendency be manifested or not.

The motion, as will be more particularly considered afterwards, may not be one of a large visible mass; it may be among the atoms or molecules of a body, and consequently so minute that it escapes our direct perception. We cannot, for instance, see the motion of the molecules of steam, yet we know that a multitude of such minute motions combine to move the piston-rod of the engine, and this in turn to move perhaps a score of waggons.

124. Moving matter, then, or matter in motion is the *expression* of force. Yet we may have force really existing unexpressed, possible, or *potential*, though ready to appear as motion at any moment.

As, for example, a boulder on the face of a hill may be kept from moving merely by a small stone in front of it. It may lie for years and never exhibit its force, while the mere removal of the little obstacle will allow the exhibition of an enormous impetus. For this reason we must include in the idea of force, not only *actual motion*, but also the *tendency to motion.*

" *Various kinds of force.*"

125. In nature we find many kinds or modes of manifestation of force; but they all agree in this, that they either actually produce, or tend to produce some sort of material motion.

The force of *gravitation* is, as we have seen, universal. It gives shape to our earth and all the heavenly bodies, and is the source of all our water-power, of the motion of clocks driven by weights, and of all motion due to the effect of falling or heavy matter.

It is the force of *cohesion*, again, that we have to overcome when we break a stone, stretch india-rubber, tear a bit of paper, saw wood, or file a piece of brass. And, though the force appears, in these cases, more as a passive or conservative one, merely *resisting* the tendency to motion, it is nevertheless capable of exhibiting active motive power: the reason that it does not usually appear to do so, being due to the very limited range through which the force acts. When, however, we let go the string of a bent bow, the activity of the cohesive force of the bow is exhibited in the motion of the arrow.

Chemical force operates within still more minute distances, and we cannot see immediately its manifestation as motion. But in the projection of a cannon ball by the explosion of gunpowder, we have an obvious proof that it does not differ from other forces in this respect.

The forces of *heat*, *electricity*, *magnetism*, and *light* are now considered to be all species of motion, discoverable and measurable only by the amount of movement they can produce or counteract.

" *Measure of force.*"

126. *The measure of a force is the momentum or quantity of motion it can produce in a given time, which will obviously depend both on the velocity and on the mass of the moving body.*

If a single pound of matter were moving at the rate of one foot per second, it would possess a definite *quantity of motion* expressed by these words; if it were moving at the rate of ten feet a second, it would have ten times the quantity; and, lastly, if ten pounds of matter were all moving at ten feet a second, this mass would possess one hundred times the quantity of motion of the first.

A hundredweight moving at any given rate possesses double the quantity of motion of a fifty-six pound weight moving at the same rate.

A railway train of forty railway carriages moving at the speed of thirty miles an hour, has six times the momentum of a train of twenty carriages moving at the speed of ten miles an hour.

So estimated, the motion of a sixty-two-pound cannon ball, moving a foot and a half per second, is the same (nearly) as that of an ounce bullet when it leaves the rifle.

A man's force will move a small skiff quickly, a loaded barge very slowly, and a large ship in a degree scarcely to be perceived.

Yet in each case the quantity of motion may be the same, and a true measure of the effort exerted.

By experiment it is found that if an inelastic ball of soft clay of one pound, suspended by a cord as a pendulum, be made to strike with a velocity of ten feet per second against another of nine pounds, suspended in the same way, but at rest, the two will start together at the rate of nearly one foot per second, the original quantity of motion being then diffused through ten times the original mass, and therefore exhibiting only one-tenth of the velocity.

A block of wood, floating against a man's leg with moderate velocity, would be little felt; but a loaded barge, coming at the same rate, and pressing it against the quay, might break the bones; and a large ship, moving slowly, would crush his body against any fixed obstacle.

Two huge floating icebergs meeting will crush a man-of-war as easily as we crush an egg-shell between the fingers.

127. In these instances we see the power of heavy masses in motion; but enormous momentum may be obtained from light masses, if moving with very great velocity.

Air, which is so light and gentle when slowly moved, exhibits tremendous force when blowing a hurricane; pulling down houses like so many hay-ricks, and uptearing trees as if they were but weeds.

The waves of the sea in a storm often possess a most irresistible violence, tossing about the largest iron-clad as if it were a lump of cork.

A most remarkable illustration of this fact appears in the irresistible force of heat. It is an inconceivably rapid quivering motion of the minute molecules or atoms of coal, which, communicated to those of water vapour or steam, excites the ponderous engines that push our trains and ships along, and may indeed be said to move the world.

128. As the resulting velocity of two bodies, moving in the same line so as to meet, is the sum of their velocities, so the whole quantity of motion they possess is the sum of their momenta, and this is the measure of the shock they will produce.

If two persons running or skating strike against each other, the clash is much more violent than if one were standing still, and the result may be dangerous or even fatal.

The meeting fists of boxers not unfrequently dislocate or break bones.

When two ships in opposite courses meet at sea, the destruction may be as complete to both as if each, with a double velocity, had struck on a rock.

If a railway train dash into another moving in the opposite direction, their resultant momentum is exhibited with terrific effect; and the destruction to a passenger train is all the more disastrous if the opposing one be a long, heavy goods train.

"*Composition and Resolution of Forces.*

129. Force, then, being estimated by ***quantity of motion*** or mass and velocity conjointly, the rules of composition and resolution given for velocities apply equally to forces.

Two or more forces may act on a body at the same instant, as, for example, in the throwing of a stone, the force of projection and the force of gravity. Each force is equivalent to a certain velocity of the mass in its direction, and the resultant force will be represented by the mass moving with the resultant of those simultaneous velocities.

Thus—(i.) If two forces act in the same line on a body—say the force of the tide and of the screw on a steamer—the resulting force will be the sum or difference of these forces, according as they agree or oppose in direction.

(ii.) If a body be influenced by two forces in different directions, these may, just like velocities, be represented by two contiguous sides of a parallelogram, and the resultant force will be represented by the diagonal of that figure, drawn from the position of the body.

A billiard ball, for instance, may be struck at the same moment with two cues, so that in virtue of the one stroke it would go in the direction A B, and in virtue of the other along A C. Now, if we take in those directions A B and A C proportional to the forces, they will, of course, be proportional to the velocities imparted to the ball per second; and since A D represents the resultant of these velocities (see Art, 115), it will be also proportional to or will represent the resultant of the two forces.

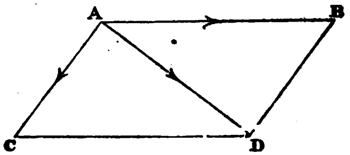

Fig. 8.

We have thus precisely the same method for finding the resultant of two forces as of two velocities: and this method is known as the *Parallelogram of Forces.*

(iii.) So the rule for the composition of any number of forces acting simultaneously is exactly the same as that for velocities (see Art. 117); and simply, as we see, because the consideration of forces really resolves itself into that of velocities.

(iv.) Similarly, a force acting on a body so as to move it in any one direction, may be resolved or supposed broken up into two in any two desired directions.

A stroke given to a billiard ball, which will make it move in the line A D, may be supposed resolved into two co-existing strokes in the directions A B and A C (fig. 8); and their amounts will be known from the proportion of the sides and diagonal of any representative parallelogram, such as A B D C, in the same way as for velocities (Art. 118).

130. The resolution of force is very well exemplified by the action of the wind on a sailing vessel, whereby the wind blowing in one direction may cause the ship to sail in a very different one; and, what is still more curious, the same wind may waft two vessels in nearly contrary courses. Were a ship equally ready to move towards either side, as, for instance, if it were in the shape of a round tub with a sail hoisted, it would be driven just right with the wind. But it is made so as to cut through the water easily in one direction, and can only with great force be moved broadside against it. When the wind is not blowing in the course of the ship, but obliquely towards it, this will be equivalent to two winds blowing, one in the direction of its course, and another across it. By long experience the sailor learns to turn his sail-yard so that the component force in the line of the ship's course may be as great as possible, and that across it comparatively insignificant. The latter is counteracted by the huge volume of water that would have to be pushed against.

Different dispositions of the sails will thus give the most effective components of force for different courses; and just as a stroke with a billiard cue in precisely the same direction will make the ball go to one side or another according to where it strikes the ball, so the same wind may be driving two ships in courses right athwart each other.

"*Uniform and variable forces; and their measure.*"

131. Force, expressed by a moving body, will be uniform or variable according as the velocity of the body is either constant or not; and its measure will be estimated, of course, in the same way as that of the velocity. Thus we speak of *uniform*, *accelerated*, *or retarded force*, according as the momentum remains the same independently of time, or increases or decreases with it. As we do not meet with absolutely isolated or free matter, so all expressed force (or moving force) is more or less variable; it comes into being gradually, never instantaneously, and it dies away also by degrees.

Variable forces alone present any difficulty in their calculation, and to these therefore—as being also the most important—we shall now turn our attention. In no case is force called into existence in a moment; whether it be produced by the earth's attraction, cohesion, chemical affinity, by magnetism, electricity, or any other means.

We shall consider the grounds for this statement in detail.

"*Examples of accelerated force.*"

132. Even in the most impulsive communication of motion there is more or less of continued, gradual, or accelerating action.

When we strike a billiard ball, it, being not perfectly rigid, receives the moving force gradually, the blow increasing from zero at the first instant of touching, up to a maximum, and diminishing again to zero when the action is complete and the ball is on the point of leaving the cue.

The action of gunpowder on bullets, appearing so sudden, is still not an instantaneous but a gradually, though rapidly, increasing one; for we find the power of projection to depend much on the length of the piece along which the force pursues the ball. A small fast-sailing vessel, with a single long gun, has compelled a superior vessel, whose guns were shorter, to yield.

The following are examples where the continuance or cumulation of the force is more apparent :—

Savages throw, with deadly effect, poisoned arrows, by blowing them through a long smooth tube with the mere force of the breath. The boy's pea-shooter is a more harmless and familiar illustration of the same kind.

When a powerful blow is intended, the fist, or hammer, or hatchet, or club is lifted high and carried far back, that there may be time and space for accumulating greater force.

Bulls, rams, and goats, in fighting, alternately recede and then run at each other, knowing that thus they increase the shock.

A horse kicking, from the great length of his leg, and the consequent space through which he can be adding velocity to his foot, drives it at last against the object almost like a cannon-shot.

A bow-string, propelling an arrow, follows it through a considerable space, and so gives the piercing power at last produced.

The battering-rams of the ancients accumulated in them the effects of many hands and of a considerable duration of action, so as to give one powerful, sudden shock.

A boy's catapult, in like manner, owes its power to the action of the elastic force of the stretched india-rubber continued through the space of a few inches.

If the mainspring of a watch were allowed to uncoil itself freely, we should see the hands moving round at a constantly increasing rate, till the whole force was spent ; and the sole object of the mechanism is merely to regulate this force and allow it to act uniformly.

" *The accelerating force of gravity.*"

133. *Gravity* is the most obvious example of accelerating force, as it is also the most important—partly from its sharing in all mechanical concerns of a practical kind, and partly from its uniformity and readiness of calculation.

Examples to show that the force of gravity is an accelerating or constantly increasing one, meet us everywhere.

A boy letting a ball drop from his hand can catch it again in the first instant, but after a little delay his hand pursues it in vain. If he throws it up and catches it, he receives a harder blow when it has fallen through a great height than if it has dropped merely a short distance.

A person may leap from a chair with impunity; if from a table, he receives a harder shock; if from a high window, a topmast of a ship, or the parapet of a high bridge, he most probably fractures bones; and if he fall from a balloon at a great height, his body will be literally dashed to pieces.

Meteoric stones, coming from great heights, bury themselves deep in the earth, by the force gradually acquired from gravitation.

When the wood-cutters among the Alps launch an enormous tree from high up on the mountain side, along the smooth wooden trough prepared as a channel, it is seen plunging, in fewer minutes than it traverses miles, with terrific velocity and force into the lake below; this final effect has been produced by the *continued* action of gravity through the whole time of its descent.

The shock or blow of the ram of a pile-engine is not the effect of a momentary impulse given by the earth, but of an attraction continued through a space of perhaps twenty feet.

A common hammer in its instantaneous shock has the condensed effect of the arm and of gravity, as accumulated through its whole previous course.

There are some long-necked birds that fight and kill their prey by blows with their hard beaks. They draw back the head, bending the neck like a swan or serpent, and then dart it forward with a continued effort, till the strong, wedge-like beak reaches its destination almost with the velocity of a pistol bullet.

Water falling from a height acquires a power according to the extent of fall; its power to turn a mill depending on the "*head*," or height of the source of water pressure. A small stream falling a considerable height will, in course of time, hollow out a solid rock. We have a striking example of the acceleration of gravity in the great violence possessed by a mountain stream at the base of a mountain, compared with that high up on its side.

Soft snow in falling from the precipitous sides of the Alps gathers tremendous force as an avalanche, and with a sound like thunder rends and carries before it trees, rocks, and all other obstacles in its course.

But for the resistance of the air breaking the force of a waterfall, it would gradually penetrate deeply into the ground.

Any liquid falling from a reservoir forms a descending mass or stream, of which the bulk diminishes from above downwards in the same proportion as the velocity increases, as is well exemplified in the pouring out of molasses or thick syrup. If the height of the fall be considerable, the bulky, sluggish mass which first escapes is gradually reduced, before it reaches the bottom, to a small thread, but the substance of that thread is moving proportionately faster, and fills the receiving vessel with surprising rapidity.

The same truth is exhibited on a vast scale in the Falls of Niagara; when the broad river is seen first bending over the precipice a deep, gently moving mass, then becoming a thinner and a thinner sheet as it descends, until at last, surrounded by its foam or mist, it flashes like lightning into the deep below.

"*Gravity is a uniformly accelerating force.*"

134. A thousand such instances might be given to show that gravity is an accelerating force, but they do not tell us what is the rate of acceleration or the *rate of increase* of the speed and momentum, or they do so only very roughly.

By the special contrivance known as Attwood's machine (see page 62), or more roughly by dropping a heavy body from successive heights and noting the times of fall, we find that the acceleration takes place at a *uniform rate.* That is to say, a falling body receives equal additions of velocity and of momentum during each successive unit of time.

If we let a stone drop vertically, as from the parapet of a bridge, we find it falls through about 16 feet in one second, through 64 feet in two seconds, through 144 feet in three seconds, and so on. But, after the body has fallen for a second, or through a space of 16 feet, it is found to have a velocity of 32 feet per second, and in two seconds it is found to have one of 64 feet, in three seconds of 96 feet, and so on. Thus the velocity at the end of two, three, four, &c., seconds is double, triple, quadruple, &c., what it is at the end of one second; that is, it increases by the same amount, viz. 32 feet per second, during each successive second of its fall.

Consequently the momentum increases in the same proportion, or the force of gravity is uniformly accelerating.

We measure the force of gravity, then, as we do any other force, by the quantity of motion it imparts to any mass (chosen as our unit or standard), such as a pound or an ounce, in a second (unit of time).

Usually it is expressed not exactly in this form, but in one easily convertible into it. The force of gravity is commonly quoted as a *velocity of* 32 *feet per second*, for this reason, that *any mass* falling freely under the action of gravity acquires this velocity in one second from starting. Let us see why this is so.

"*All unimpeded bodies fall equally fast.*"

135. It does not quite accord with popular notions that all bodies, light as well as heavy, should acquire the same velocity by the same duration of fall. For we see a feather, dropped along with a sixpence, lag behind in its descent, and we imagine its gravitating power less energetic. Weight for weight, however, this force is precisely the same for both; only the interference of the air has most effect on the feather, which, for the same velocity, has a much less *quantity of motion* than the sixpence. As we remove the obstruction of the air the discrepancy vanishes; thus, a piece of gold leaf falls more slowly to the ground than a half-sovereign, but, if the gold leaf be rolled into a small ball, it has now a smaller mass of air to oppose it, and it drops as quickly as the coin.

So, too, the feather and sixpence, when dropped within a long tube or other glass vessel from which the air has been removed, are seen to fall side by side.

The reason of this is obvious. A regiment of soldiers marches no more quickly along the road than a single man, where each merely carries his own burden and has his own power within him. But in the push against difficulties the weak goes to the wall. So a million of particles, bound side by side in one common mass, gravitate to the earth by virtue of the power innate in each individual particle, and it is the interference of the air which bears harder on a few particles than a large company. Could we live on a globe devoid of atmosphere, then the lightest dust would fall at once to the ground as quickly as we see a stone fall.

"*Attwood's Machine.*"

136. We should infer, then, that, if it were possible to increase the mass of a body without at the same time, and in the same degree, increasing the attracting force of the earth for it, there would no longer be the same rate of fall. It is so.

This is shown by a beautiful, though simple, contrivance, invented in the end of last century, by Mr. Attwood, of Cambridge.

Essentially it consists of a pulley, P, or wheel with a grooved edge, of about six inches diameter, over which are balanced two equal weights, *a*, *b*, attached to the ends of a long silk string. The pulley has its axle, *d*, laid on what are called friction wheels, *e*, *f*, to give great delicacy of motion. We may thus look on *a*, *b*, as two masses freed from the action of the earth's gravity, since each just counteracts the other's weight.

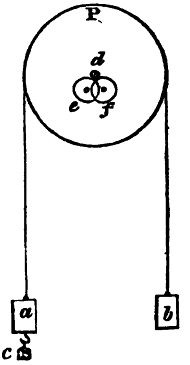

Fig. 9.

Suppose that *a* and *b* are masses of one pound each; then, if we hook a mass of an ounce, *c* to *a*, the action of the earth will cause *c* to move down; but *c* has to move not only its own mass, but also the masses *a* and *b*, which gives altogether thirty-three times the mass of *c*. Hence the motion produced will be correspondingly slow, and the velocity attained at the end of a second will be only $\frac{1}{33}$rd part of the usual free velocity (32 feet), that is, only about a foot per second. In this way the rate at which a mass falls to the earth can be made as slow as we please, so that we can study most accurately the above laws as to the quantity of motion. This gives to Attwood's machine a great importance, as it enables us to verify experimentally several of the abstract laws of motion.

137. Attwood's machine is in principle just a very delicate kind of weighing-beam. If we have in the two scale-pans of a nice balance two weights exactly equal—say, a metal pound and a pound of sugar—the addition of a little sugar to the one side will make that scale move slowly down, and all the more slowly according as we increase the counterpoising weights in the scales; the same addition will have less effect with two pounds weight in each scale, still less if we have five pounds.

138. By means of this contrivance, then, as well as by others of more recent invention, we can calculate to any degree of nicety the heights fallen through in one, two, three, &c., seconds by a heavy body, and so we can trace the changes upon its velocity. It is deduced from the average of a great number of trials, that a body drops through 16·1 feet in the first second of its fall, and has acquired in this time a velocity just double, i.e., of 32·2 feet in a second; that is to say, it would continue its course at the rate of 32·2 feet per second afterwards, if the earth's attraction were instantly to cease at the end of one second. The reason of this is manifest; for at the end of the first half-second, the velocity would only be 16·1 feet, and at any instant before the middle of the second, its velocity would be just as much less than 16·1 feet as it is greater at the corresponding instant after; so that the velocity on the average is 16·1 feet per second. Or it may appear more plain in this form:—Suppose we take ten seconds in place of one; the velocity at the end of ten seconds is 322 feet per second, and the space fallen through is known (by a simple calculation to be explained presently) to be just 1610 feet, that is a space which it would have passed through in the same time with a uniform velocity of 161 feet, or just half of its final velocity. Now, at the end of five seconds its velocity would be just 161 feet per second; and, a second before that, it would be as much less than 161 feet as it is greater than that a second after. Thus the velocity acquired, after the middle of the time, above the average, exactly compensates for the previous lack of velocity below the average. It is therefore a necessary consequence, from the uniformity of the acceleration, that the final velocity be double of the *average* one for any time.

139. In the next second the body falls through 32·2 feet in virtue of the velocity already acquired, and also through an additional 16·1 by the continued action of gravity; or, in all, three times as far as in the first second. So that, in two seconds, it falls altogether four times as far as in one second.

At the end of two seconds the velocity acquired is twice as great as at the end of one, or is at the rate of 64·4 feet per second.

Thus, during the third second the body falls through 64·4 feet and other 16·1, in all 80·5 feet, or five times as far as in the first second. In three seconds, therefore, it has descended nine times as far as in one second. And so on.

Thus the spaces fallen through in successive intervals of one second each, are in the proportion of the odd integers—1, 3, 5, 7, 9, &c.

And the whole spaces passed through at the end of 1, 2, 3, &c., seconds, counting from the commencement of the fall, are proportional to the squares of these numbers—that is, are as 1, 4, 9, 16, 25, &c.

These facts may be presented in the following tabular form:—

	1st Sec.	2nd Sec.	3rd Sec.	4th Sec.
Velocity at end of	32 feet	64 feet	96 feet	128 feet.
Space fallen through during . . .	16 feet	48 feet	80 feet	112 feet.
Whole space fallen through to end of	16 feet	64 feet	144 feet	256 feet.

They also admit of illustration by producing a number of small triangles in a large right-angled triangle, as in fig. 10. These lesser triangles are alternately inverted, and, for the sake of distinction, alternately shaded and white. The perpendicular side of the large triangle is divided into any number of equal parts—1, 2, 3, 4—which may represent equal portions of time (seconds). Lines are drawn from these points so as to be parallel to the three sides of the triangle. The smaller triangles or spaces are thereby produced. It will be perceived, by reference to fig. 10, that in the first second, a falling body falls through *one* space or triangle. The space passed through in the second period will be represented by three triangles, two shaded and one white, which, added to the first, will make *four* spaces. So with the third period, five spaces, which, added to the preceding, make *nine*, and with the fourth period seven spaces, which, added to those already passed, make *sixteen*—1, 4, 9, 16.

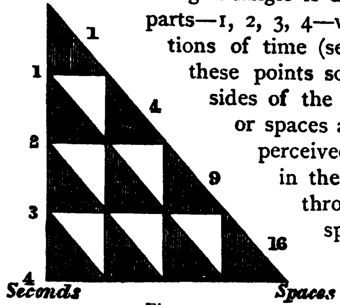

Fig. 10.

140. Knowing this rate of progression, we may easily compute the velocity acquired by a falling body and the distance through which it falls in any time; and the height of a precipice, or of a bridge, or the depth of a well, may be ascertained by marking the time required for a body to drop through the space.

141. Such being the law of the velocities produced by gravity, we have at once the means of knowing the amount of force or *momentum* expressed from gravity in any time or during any length of fall.

The moving force possessed by a ton hammer falling for half a second would be expressed as a mass of one ton moving 16·1 feet a second, or 16·1 tons moving at a rate of one foot a second; and if it fall for a length of time twice, thrice, or four times as long, its moving force would be just twice, thrice, or four times increased.

Thus, should we wish to double the blow which a pile-engine head gives, we should have to double the *duration* of its fall; but that implies that we should have to do more than double the *extent* of its fall; we should (see Table, Art. 139) have to quadruple its former extent of fall. So that, if it fell before through ten feet, in order to give double the blow it would have to be dropped through forty feet.

It is interesting to reflect that a railway carriage going fifty miles an hour has the same amount of moving force as it would have by falling through a height of thirty-six feet. When we think of the force which a stone of a hundredweight would acquire in falling through such a height, we need not wonder at the fearful results of railway collisions.

142. We have assumed that the *momentum*, or velocity and mass together, are a proper estimate of any force. This can be directly shown with Attwood's machine.

We add any mass, W, to one of the balanced masses, A and B, to act as the moving power. Now, as the force which the earth's attraction for W generates in any time must be the same whatever masses A and B have, we find that this force produces in the same time a double or triple velocity when the mass is reduced to one-half or a third : and it produces a half or a third of the velocity when the mass is doubled or tripled.

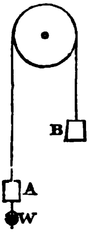

Fig. 11.

If A and B be each 15½ ounces, and W one ounce, we find A move down with a velocity at the end of one second only $\frac{1}{32}$ of that acquired by falling freely ; that is to say, of about one foot per second.

Again, if A and B be each 31½ ounces, while W remains one ounce, then the velocity produced in the whole mass at the end of one second would be only one-half foot per second. But the whole amount of gravity must be the same in both cases, and the same as would be on the weight, W, falling alone ; when it has to move more than its own mass the force is correspondingly diffused and the velocity correspondingly lessened.

143. In the practical application of these facts, allowance must of course be made for the interference of the air ; this increases with the increase of velocity in the falling body, and becomes ultimately so great as just to counterbalance any increase of velocity from gravity ; so that if the height from which a body falls exceed a few hundred feet probably, the motion would ultimately become uniform. This is similar to the balance that sets in between the accelerating force of a steam-engine, and the friction or loss of apparent force between the wheels and rails.

144. Attwood's machine gives us the means also of showing what is meant by, and of measuring, the velocity *at any instant* in the case of a constantly varying motion. This is effected simply by putting the additional weight in the shape of a bar on the top of the weight, A (fig. 11), and fixing a ring on a stand, so that while A moves down vertically it passes through the ring and leaves the bar behind, and goes on at a *uniform* rate afterwards in virtue of the velocity it had acquired at the instant that the bar was removed. With the means of adjusting the ring to any height we please, it is obvious that we can ascertain the velocity at any instant. Thus we actually realize the definition of a varying velocity, viz. that it is the space which the body would describe in the unit of time *if at any instant its velocity were suddenly to become uniform.*

"*Retarded force.*"

145. The transference or transformation of force between masses is in no instance absolutely instantaneous.

We have seen that force is in no case produced instantaneously, but always with more or less of acceleration. So we may say, in like manner, that force can in no case be made to disappear instantaneously, but only more or less gradually.

The *rate* at which this transference takes place may be various; the force of a body may be exhausted regularly or irregularly.

As the velocity and momentum of a falling body are gradually increased and at a uniform rate, so in an ascending body they are uniformly diminished.

A bullet, shot directly upwards, loses every instant a part of its velocity and force, till at last it comes to rest in the sky, and there a soaring eagle might see the messenger of death motionless and harmless for a moment, ere it start again on its downward course.

146. The following examples show the gradual nature of all retardation of force :—

The shock of two railway carriages meeting, is prevented or lessened by the resisting elasticity of the buffers which gradually overcomes the motion.

It is soft gas expanding that begets gradually the death-carrying force in the cannon-ball; and soft air, or cotton, or wool, resisting in a strong, close tube—if the bullet could be directed exactly into it—would again gradually absorb the moving force from the ball.

Were the attempt made, however, to stop the ball suddenly by a block of the hardest granite, the block would be shivered by the blow.

Bales of cotton or thick masses of cork attached round a ship will receive cannon balls, and bring them to rest, without themselves suffering much, while the naked firmer side of the ship would be penetrated. The cotton or cork offers an increasing resistance through considerable space, while the oak opposes its hard front at once and must instantly suffice or be torn.

A hard body, that it may at once destroy such a motion as we are supposing, must be able to oppose as much force in perhaps the hundredth of an inch, that is in the extent to which its elasticity will let it yield without breaking, as the moving cause gave through a much greater space; and, when it cannot do this, it must be penetrated by the moving body.

Could we suspend a vast mass of rock like a pendulum, and cause it to swing down from a considerable elevation, it would arrive at the bottom (or vertical line) with force sufficient to shake a thick wall or rampart to its foundation; but if it were merely allowed to continue its course like a pendulum, and ascend on the other side, the continued action of gravity now opposing its motion would bring the great mass to powerless rest again, just when it had reached an elevation equal to that from which it fell.

A heavy ship moving quickly with the tide or wind could not be stopped instantly by a short rope or chain of any magnitude; if the attempt were made to stop at once so vast a momentum, something would certainly give way. But a rope of very moderate size kept tight between the shore and the ship, and from time to time allowed to slip a little round a wooden block, when the tightness threatened its breaking, would accomplish the end very soon and safely.

A hempen or silken elastic rope supporting the scale of a weighing-beam would, for a similar reason, resist a greater weight *falling* into the scale than would be resisted by an iron chain, which, however, would be stronger than the rope for bearing a *quiescent* weight.

On the other hand, iron is stronger than hemp or rope when used as a chain cable for a ship to withstand the sudden force of waves. This will be understood on considering that the heavy chain hangs as a curve in the water, while the rope, being nearly of the density of the water, is supported in it almost as a straight line from the anchor to the ship: therefore when a great wave dashes against the ship, the bent iron chain will have a sort of elasticity from its great weight, and offer a continued resistance till it is drawn nearly straight; but the straight rope can yield by its elasticity only a very little way, and its weight is of no consequence in the resistance.

"*Laws of motion.*"

147. After these general explanations of force, and the means and mode of its measurement, we are prepared to understand Newton's famous Laws of Motion; and we shall now consider these in detail, as they are much more comprehensive than at first sight appears from the simple statement of them.

The first Law of Motion may be given thus:—

A body free from the interference of external matter or force will either remain for ever at rest, or will move uniformly in a straight line.

Absolute proof of this, we may remark, it is impossible to find, because we never see matter entirely isolated, free from the action of other matter and of outside force. Still we can be certain of its truth by the same kind of reasoning as we employ in many inductions from experience. Finding that any departure from agreement with this law is distinctly traceable to some external interference, and that the more we can remove all external forces the more nearly we approach to a complete realisation of the principle, we conclude that, were it possible to get rid of every outside influence, we should see the law operating in perfection.

148. The first part of the law no one will deny. A body at rest requires force to set it in motion. Keep this away, and the object will sleep through all time, dead as the everlasting hills.

Stated thus, there is not the least difficulty about it. But when we expand the statement, or view it from the other side, and say that the action of the smallest force on any mass at rest must produce a corresponding amount of motion or departure from this state of rest, we come in contact with a popular prejudice—known under the name of the law of *inertia*—that conceives matter at rest as offering a positive *resistance* to be set in motion.

The ideas attached to the use of the words *inertia*, *inertness*, *deadness*, *and resistance of matter*, being often confused and erroneous, require some elucidation.

"The so-called inertia of Rest."

149. When we put our hand to lift a heavy weight or to turn a heavy fly-wheel, we seem to experience a resistance or unwillingness of the mass to be set in motion, a sort of stubbornness which it takes some time to overcome, as if by our efforts we had to persuade the mass to move. This is, however, but a metaphorical and illusory inference from our own feelings.

We have already explained that the measure of any force is dependent on the mass or quantity of matter moved and the velocity conjointly; it follows that, when a body of smaller mass imparts its force to a larger body, the latter will not move off with so great velocity as the former; and before it can acquire its speed, it must receive a succession of impulses from the small body. Now, it is this *change of velocity* in the transference of force that seems to countenance the idea that matter at rest offers a *resistance* to be set in motion. When we move a fifty-six pound weight, the velocity generated will be very much less than in the case where the hand alone is moved with the same effort; and the seeming unwillingness of the mass to move is but an erroneous mental inference from this fact.

150. Such is the proper explanation in the following examples, usually given to illustrate the stubbornness or inertness of matter:—

The light wind blowing, even with a high velocity, on the newly-spread sails of a ship, will not impart at once a like speed to the heavy vessel. A continuous blowing, that is, a constant succession of such air-impulses, is needed to give it swift motion, or, as it is commonly put, before the inertia of the vessel is overcome.

The starting of a long railway train, by the powerful motion of the comparatively diminutive piston of the engine, exemplifies the same principle.

Horses starting a carriage expend repeated efforts before its motion is equal to what theirs would be with those efforts, if detached from this addition to their mass.

A man lying down and receiving the blow of a forge-hammer on his chest would be instantly killed by the sudden inward pressure; but if he can suffer an anvil to be laid on his chest the blow may then be given with impunity. The blow diffused through the enormous mass gives a velocity so trifling as to be uninjurious.

151. Where one moving body meets another not directly, but very obliquely, so that their surfaces just graze, in general only a small quantity of the motion of the first will thus be communicated to the second; and it requires long continued rubbing, or friction, that the whole may be transferred. The rubbing surfaces are in no case perfectly smooth, and we may suppose the motion communicated by the impacts of minute projections or protuberances on each surface; and, of course, the rougher the surfaces, or the greater the friction between them, the more rapid will be this communication of the motion, because the nearer it will approach direct impact of the masses.

Now many of the examples usually given of inertia merely exemplify the fact that the imparting of force by friction, is necessarily more tardy in producing velocity than by direct communication.

Of this class are the following examples :—

If a shilling be laid on a smooth card balanced on the tip of the finger, a sharp blow against the edge of the card will cause it to dart off, leaving the shilling apparently undisturbed on the finger; the momentary friction was not sufficient to give the mass of metal any perceptible motion.

So a person standing carelessly at the stern of a boat, or on the step of an omnibus paying his fare, may, by a sudden start of the vehicle, be left behind.

An awkward rider may be left behind by his horse starting off suddenly; or he may be thrown to one side by the horse starting to the other.

A person in a carriage has his head thrown against the cushions when the carriage is first put in motion: because he is not glued rigidly to it, so as to take its velocity at once.

In those dreadful railway collisions which are but too common in our day, a passenger facing the engine will be dashed on his face and receive a blow on the forehead, while one sitting with his back towards the engine will receive a no less deadly blow as from a hammer on the back of the head.

152. If the parts of a body be stiffly connected, any force imparted to the body will produce a similar velocity of all the parts. But if the connexion between the parts be elastic, or not rigid, one part may be moved, and the force communicated through the elastic connection will not be sufficient to give the other part equal velocity, the two parts will not move together, but one part will seem to wish to remain behind the other.

Thus, if a glass of wine be suddenly pushed forward on a table, the friction between the liquid and the glass is not sufficient to allow communication of equal velocity to the liquid, and the wine is left behind on the cloth.

A servant carrying away a tray of glasses or china quickly may let some drop from this cause.

A broad basin filled with liquid, such as a tub of water or a plate of soup, must be very gently carried, so that the friction between the liquid and vessel get time to generate a velocity in the liquid equal to that of the basin.

The operation of beating a carpet, or of a sheep shaking off the snow or wet is similarly explained.

A weight suspended by a spring on ship board is seen vibrating up and down as the ship pitches with the waves. It seems to fall as the ship rises, and rise as the ship falls; but the motion is mostly in the ship, that which is transmitted through the elastic support not being sufficient to give the heavy mass a sensible velocity.

A heavy weight so supported and connected with a pump-rod has been caused to work the pump.

Like the weight last mentioned, the mercury of a common barometer on ship-board appears to be constantly rising and falling in the tube as the ship pitches; and until the important improvement was made of narrowing a part of the tube to prevent this, the mercurial barometer was useless at sea. The explanation is that the tube rises and falls with the ship from being affixed to it; but as it rises, the friction between the glass and mercury is not sufficient to communicate to the heavy liquid a motion *equally quick* with that of the tube; and we, rising with the vessel, and unconscious of our real velocity, interpret the insensible velocity of the mercury as a falling down instead of a slight rising, which is actually the case. So when the ship pitches suddenly down, its motion is more rapid than that which gravity imparts to the mercury, and accordingly the mercury seems to rise in this case.

The well-known mode of supporting a ship's compass-box on gimbals—which may be called a sort of universal pivoting—is another illustration of the same natural law. An interesting and useful one also is Bessemer's invention, which is intended to alleviate the sorrows of the sea-passage from Dover to Calais, and which consists in suspending a whole cabin or saloon in the middle of a steamer, so as to move about a longitudinal axis parallel to the keel. As there is no part of the vessel fixed, there would of course be more or less oscillation set up in the saloon by the rolling of the ship; but, by an ingenious application of hydraulic machinery, Bessemer places the *damping* of these oscillations under the control of one man, whose duty it is to keep the floor of the saloon horizontal, being guided by a spirit level in front of him, just as the helmsman is guided by the compass.

A heavy mass, balanced by springs within a frame and carrying a pencil, may by its comparatively insignificant motion be caused to trace, on a sheet of paper rigidly fixed to the frame, all quick motions of the latter. In this way the tremors and heavings of the ground in earthquakes can be recorded, or the severe jolts of railway carriages can be made to indicate defects in the road needing repair.

153. The second statement in this First Law of Motion is, that a body once in motion will continue to move *uniformly*, if no external force interfere. In other words, any change in the velocity or the quantity of momentum of a moving body is due to the action of some external matter or force.

Prevent this, isolate the moving body from all other matter and force, set it in motion, and in eternal, perpetual motion it will continue so long as it traverses *absolutely empty* space. Here, again, we seem to be contradicted by the experience of every-day life, and the common prejudice founded on it, that moving matter has somehow a *tendency to rest*, and that motion is an *unnatural* and more or less temporary condition. All artificial motions, and all natural motions around us on the globe tend, sooner or later, to cease: we may make a clock to go for a week, or a month, or even a year, and we admire its ceaseless activity whether we wake or sleep. But stop it ultimately must; rest is the fate which there is no escaping. *The grand mechanical impossibility is a perpetual motion.* And why? Simply because we cannot annihilate the action of all external forces. Do what we may, we can never eliminate the interference of friction alone; until we can poise a ball in utter vacuity and produce a perfect copy of the planetary and stellar masses we must be content to bear the doom of our condition—the gradual leakage of all force by its diffusion through surrounding matter. Friction of the air and of other matter is the great draining force which tends to stop all motions on the surface of the earth; but the more that we lessen this, the nearer we come to realize the truth of this second part of the law of motion—that motion is as natural and as persistent as rest if left absolutely free.

154. The illusion of this idea of preference for rest will appear when we consider the following illustrations :—

A top or a gyroscope may keep up its motion for ten, twenty, thirty, minutes or more : but sooner or later the whirling ceases, simply because there is a gradual transference of its momentum to the surrounding air—where the motion ceases to appear—and to the molecules near the point of support in the shape of an invisibly minute heat-quiver. If we set the top spinning inside a vessel from which we can extract the air, it will go on whirling for hours, because one of these avenues of expenditure is closed. From this we are justified in concluding that could we put it in motion in an *absolutely empty* space, and *free from contact with any other matter*, it would never stop.

Practically, it is impossible to do this. There is always more or less transference, diffusion, or apparent loss of visible motion at the points of support of any contrivance, however fine these may be made; everything is, moreover, bathed in an ocean of air particles, and these take up part of the motion and lead to its gradual disappearance.

A pendulum, or a leaden ball hung by a fine silk thread, will swing only for a few minutes in air before this friction destroys its motion. In a vacuum it may vibrate for nearly a whole day, because the only source of leakage is at the point of support.

So a ball rolled on level grass soon stops; rolled over a smooth floor it goes on longer, and on smooth ice much longer still, the loss by friction being then reduced to a minimum.

155. It is only in the celestial spaces, however, that we see motions completely freed from the interference of air or other matter, and there they seem eternal.

Had the human eye, unassisted, been able to descry the four beautiful moons of Jupiter wheeling around him for these thousands of years with such an unabated regularity that they now form to the astronomer an unerring time-piece in the sky, the prejudice that motion is always tending to rest would never have arisen.

Science has proved that the velocity of our globe, in its present orbit, was thousands of years ago exactly as it is at the present day; and that the length of the day has not varied by so much as a second. And this is simply the result of the perfect vacuity of inter-planetary space. Had we been moving through an atmosphere even a hundredth part as heavy as that which we breathe, our globe would have long ago ceased its whirling, and fallen, by a spiral course, into the sun. But for this emptiness of the celestial spaces and the consequent uniformity of the earth's movements round its axis and round the sun, we should have no rational idea of *time*: we could have no proper conception of events in the past or anticipation of them in the future. Next year, next month; even to-morrow, would not mean the same length of time as last year, last month, or yesterday. We should have no standard to go by; no fixed stars of reference to calculate our rate of passage over the ocean of time; no foreknowledge of the happening of eclipses of the sun and moon; no regular routine of the seasons to direct the commerce and concerns of the world; nothing but unimaginable confusion.

156. In actual experience we can see only the *tendency* to this persistence of force in any moving body, because friction is always present in a greater or less degree to drain away the momentum of even the heaviest moving mass.

When the steam is turned off in the engine of a railway train or of a steamboat, the momentum of the train or boat is gradually communicated in the shape of friction to the little particles against which the moving surfaces in each case graze. These masses are so small that it takes necessarily much longer time to transfer the momentum than if the body dashed against a large obstacle.

So again, when a carriage is suddenly stopped, a man will be thrown on his face; because he had a common motion with his vehicle, and while that of the latter is given up suddenly by impact or powerful friction, only a small fraction of the person's motion—as much as can be transferred through the friction between him and the vehicle—is given up in the same time. Hence, while the vehicle is brought to rest, the person still possesses most of his motion, and falls forward in consequence.

A horse stopping suddenly, thus throws his rider over his ears. Jumping from an omnibus or a railway carriage in motion is so dangerous, because while the feet soon give up their motion by friction to the ground, the upper part of the body is not brought to rest, and it is dashed to the earth round the feet as a pivot. If, however, the person run for a short distance, he may be able to bring the other parts of his body to rest simultaneously with his feet.

A man or a horse, when racing, cannot at a given signal stop instantly, because friction is the only means at his command for bringing him to rest. It is because this resistance is very much lessened that the skater cannot stop so readily as he could running at the same pace on a common road.

If a tumbler of water or a tray of glasses come in contact with some obstacle, the contents, having no solid connection with the vessel, cannot be stopped so readily, and the water or glasses will be thrown forward on the floor.

The greater momentum of the heavier greyhound cannot be so sharply counteracted as that of the hare, and this enables the hare to save itself by "doubling," or turning its course when the enemy is close at hand.

The action of shaking the snow from one's feet by kicking against the doorstep; the cleaning of dusty books by striking them together; the drying of a wet mop or of a pen by shaking—are all similarly explained.

A package containing any fragile articles, such as glass or eggs, if very suddenly dropped on the ground, or lifted even for a short distance, frequently has the contents damaged.

On the awful occasion of a ship at full speed coming suddenly on a sunken rock, all things on board, men, guns, and loose furniture, start from their places and dash forwards; the connection between them and the ship not being sufficiently rigid to convey enough of the shock to stop their common forward motion as suddenly as the ship is stopped.

The same principle explains the jolting motions felt in riding in a carriage over a rough road, or when a train passes "points" at a station. And, indeed, but for this inequality of motion in any carriage, we should not be aware that we were moving at all. In a dark night and calm sea, a person on the deck of a steamboat cannot tell if he be moving quickly or slowly, or if he be in motion at all. A ship becalmed at sea may, as numerous accidents have proved, be carried by rapid currents in any direction without one of the crew ever suspecting it; and if the suspicion do arise, the truth can be come at only by such means as the sounding line, or careful observation of the stars.

A man in a balloon, going even eighty miles an hour, knows not in what direction he is moving, nor that he moves at all, but by observing distant objects within his view.

This explains why we are not sensible of the motion of the earth itself, though we know that its circumference of nearly 24,000 miles turns once round in twenty-four hours, and that near the equator, therefore, we are actually rushing through space at the rate of 1000 miles an hour. And the reason that a lofty spire or an obelisk stands more securely on the surface of the earth than even a short pillar stands on the bottom of a moving waggon, is not that the earth is more at rest than the waggon, but only that its motion is smooth and uniform. But, if there were any jerk or sudden change of its velocity for even the smallest moment of time, we should be instantly dashed across its surface, and our noblest edifices and our imperial cities would be strewn like so much dust over the land.

157. Lastly, this First Law of Motion asserts that absolutely free motion is uniformly *straight*, and, that when any motion is not straight, some external force is causing it to deviate.

The tendency of a body to pursue its course in a straight line is unpleasantly illustrated by the overturning of carriages in quickly rounding corners; while the wheels are suddenly pulled round by the horses into a new direction, the persistence of the previous motion in a direction across that in which the carriage can move causes it to upset. Thus a loaded omnibus running south, may, when turned suddenly to the east or west, strew its passengers or any loose articles on the south side of the road.

Where a sharp turning is unavoidable in a carriage road, or on a line of rails, the outside of the bend should be made higher than the inside, that this force, which would overturn a carriage, may be expended in raising it up on that side to which the fall would take place.

The tendency of moving water to keep on its straight course is seen in the wearing away of the outside bank or a stream where it takes a sharp bend. Every turn in the course of a river indicates the action of some force which must have operated at some time, possibly ages ago, to make it deviate from the straight course.

A stone revolving in a sling, the moment it is set at liberty, darts off as straight as an arrow, and it is only because the point of the circle from which it should depart cannot in practice be readily determined that the same sure aim cannot be taken with a sling as with a bow or a gun.

On first approaching this subject one might suppose that a body, which for a time has been revolving in a circle, should naturally continue to do so when set at liberty.

We see a top whirling, and we usually imagine that there is merely one force—that of rotation—concerned in the case, and that this is of itself sufficient to keep it spinning could we eliminate friction. But since a circle may be regarded as an infinite number of minute straight lines, the course of any particle of the top is being constantly turned aside into a new direction, and this is due to the action of some interfering force in that direction. There is little difficulty in seeing how natural this is when we speak of a small body or a mere particle whirling round a point at some distance from the particle; it is only when we think of a large mass turning round itself—that is, round some direction within it as an axis,—that the misconception arises. The experience of our earliest years teaches us this fact. The merest child, when he whirls his ball round his head by a string, knows that *string* is necessary, as well as force of arm, to keep it whirling, and that if the string break, away goes the ball.

"*Centrifugal force.*"

158. The force which the string exerts, and which is necessary to keep up the circling motion is called the *centripetal*, that is, *centre-seeking* force, or *centrifugal*, i.e. *centre-flying* force, if we consider it from the other side as straining the string; or, more generally, either is termed the *central force.*

If we whirl a ball at the extremity of an elastic cord, this force is seen and may be measured by the extent to which it stretches the cord; if a rapid whirling be given to it, the string may be stretched beyond its power of restraint and snap.

In the case of our supposed whirling top, the strings which tie its particles to the centre or axis of motion are the invisible cohesive forces between them; and, just as with the ball and elastic cord, there is the same pulling, tension, or tendency of the particles to fly outwards from the centre. If these cohesive forces were to cease for a moment, the particles of the whirling top would be instantly scattered in straight lines away from the centre in every direction, just as a pin or any loose body, laid on the surface of a flat revolving top, is instantly thrown outwards, because it has no tie to the centre. (Fig. 12.)

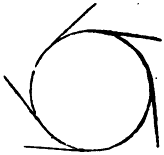
Fig. 12.

159. The following examples show the reality of this central force in any case of rotatory motion of a body :—

In a corn-mill the grain, passing through a hole in the upper or turning stone, falls between the stones, and moving round between them is, by the centrifugal force, gradually conveyed outwards to the circumference, where it escapes as flour.

If the rotation of a heavy wheel or grindstone be made very rapid, the material near the circumference tends outward so strongly by its centrifugal force, that it may be even torn away with extreme violence. This not unfrequently happens with the grindstones used for sharpening needles, the fragments scattering destruction around like a discharge of musketry or the bursting of a bombshell.

Were a man to lie down on a quickly-turning horizontal wheel, with his head near the edge, he would soon fall asleep, or might die of apoplexy from over-pressure of blood on the brain.

A pail of water may be whirled round the body horizontally, or round the head vertically, without spilling a drop, the centrifugal tendency being great enough to overcome the tendency of the liquid to fall out.

In feats of horsemanship at a circus, the rider is seen to lean inwards when moving fast in the ring, and if the horse be at full gallop, both horse and rider must lean nearly half towards falling on their side. This is to counteract the centrifugal force, which would otherwise throw both to the opposite side; if the horseman tends to fall inwards, he has merely to quicken his pace a little; if to fall outwards, he has to slacken it, and all is right again. The same inclining is seen when, in riding on a bicycle, a person keeps turning in a circle.

A coin dropped on the floor or table often describes several turns of a spiral before falling flat on its face; it is the centrifugal part of the moving force which keeps it up until by the gradual friction on the floor it is reduced so as to be unable longer to counteract the weight of the coin.

If a pair of common fire tongs, suspended by a cord attached to the top, be made to turn by the twisting or untwisting of the cord, the legs will separate from each other to an extent depending on the speed of rotation, and will again collapse when the turning ceases. The illustrious Watt adapted this simple fact most ingeniously to the regulation of the speed of a steam-engine. His *steam-governor* may be described as a pair of tongs or rods jointed at their top, and carrying heavy balls at the lower ends to make their opening more energetic. They are connected with some turning part of the engine, so that if it move too fast the balls fly asunder, and by so doing are made to turn a valve and reduce the quantity of steam admitted to the piston; or, on the other hand, if it move too slow, they collapse and allow this throttle-valve to open.

Water in a vessel caused to spin round is, by centrifugal force, raised up all round against the sides of the vessel, forming a hollow liquid basin.

Wet linen may have its moisture shaken out of it by putting it in a cylindrical case with holes pierced all round, which is caused to whirl with considerable rapidity.

A half-formed cylindrical vessel of soft clay, placed on the centre of the potter's table—which is made to whirl and is called his wheel—opens out or widens merely by the centrifugal force of its sides, and thus assists the worker in giving its form.

A ball of soft clay, with a spindle fixed through its centre, if made to turn quickly, soon ceases to be a perfect ball. It bulges out in the middle, where the centrifugal force is greatest, and is flattened towards the ends.

This change of form is exactly what has happened to the ball of our earth. It has bulged out 13½ miles at the equator in consequence of its daily rotation, and is flattened at the poles in a corresponding degree.

A mass that weighs 287 pounds at the north pole would weigh just 286 pounds at the equator, owing conjointly to the centrifugal force and the greater distance from the centre produced by the bulge.

If our earth turned seventeen times faster than it now does the centrifugal force at the equator would be nearly equal to the weight of any mass placed there, and the greater velocity would cause them to fly off altogether, or to rise and form a ring round the earth like that which surrounds Saturn.

160. The effects of centrifugal force may be exhibited as well as measured by a piece of apparatus called a *whirling-table* (fig. 13), which is a round disc of wood mounted on an upright axle, to which, by means of grooved wheels and bands, we can communicate a rapid rotation. Upon this a ball of lead may be placed, fixed at the end of a small spring, which is attached by its other end to the centre or axle of the disc.

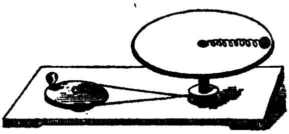
Fig. 13.

Thus, by the extent to which the ball flies out when it is whirled, we can estimate the amount of centrifugal force with great accuracy and readiness. With such an apparatus the following laws of centrifugal force may be experimentally verified, though they can be reasoned out also from general or abstract principles.

"*Laws of Centrifugal Force.*"

161. The centrifugal force in any rotating body is proportioned,

1st. To the *mass or weight of the body whirled.*

This we might expect, because each particle requires to be drawn towards the centre independently.

2nd. To the *size of circle described in a second or unit of time.*

For a body moving round a circle of double diameter has to be bent towards the centre twice as far every second.

3rd. To the *number of turns made per second* (or unit of time), and so that for *double*, *triple*, &c., the number of turns, the centrifugal force is increased *four*, *nine*, &c., times.

The reason of this increase of the centrifugal force at the square of the rate of increase of the number of turns, will appear when we consider that with, say, triple the number of revolutions per second there will be triple the number of pulls or impulses towards the centre; and as each pull has to be made in one-third of the time, it must be done with triple energy; so that, altogether, there is nine times the amount of centrifugal exertion in the second.

162. It is found that a body revolving in a circle of, say, four feet diameter, must complete its revolution in one second and a half, that it may have centrifugal force just equal to its weight.

It may give some idea of the relation of the centrifugal force to the weight of a body when we say that thirty pounds of metal at the rim of a fly-wheel six feet in diameter turning once a second or sixty times a minute, will exert an outward strain on the wheel of about one hundredweight, and if its speed were increased to five times this the centrifugal strain would amount to one ton and a quarter. If the tenacity of the wheel is unequal to bear this, such a speed would scatter the wheel in pieces.

163. The *centrifugal railway* (fig. 14) is a philosophical toy intended to illustrate the power of centrifugal force to overcome gravity. A small iron carriage, starting from A, sweeps down the incline, acquiring such a momentum at B, that it is carried round the loop, C, bottom upwards, and lands safely at its destination, D.

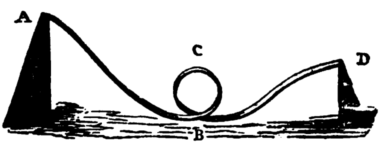

Fig. 14.

164. An artificial imitation of Saturn's ring also illustrates this subject beautifully. We provide ourselves with a square bottle, or make one with panes of common glass, and arrange in it, as shown in the figure, a spindle with a small metal disc, D, fixed on it, so that we can turn the spindle and disc by means of a crank handle, C. We next fill the vessel with a mixture of alcohol (or spirits of wine) and water of such a density that olive oil justs floats in it. Then, having previously smeared the disc, D, with oil, we pour a little oil into the liquid; it will collect round the disc and adhere in the shape of a flattened globe. On gently turning the handle we see it gradually spread out, till the centrifugal force at last ruptures it away from the disc; and it forms, while the motion continues, a miniature facsimile of the wonderful ring of Saturn.

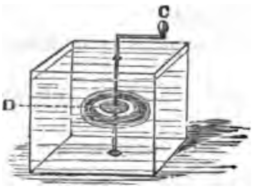

Fig. 15.

" *The Second Law of Motion.*"

165. *Any change in the amount or the direction of a body's motion must be due to the action of some force impressed on the body in the direction of that change, and is a measure of that impressed force.*

This, it will be seen, follows at once from the first law, and is in fact but an expansion of it. Let us, however, consider exactly what it implies.

When we project a ball in a horizontal direction, the force of projection would impel it straight in that line; but when we see it gradually move down towards the earth, we infer the action of another and a vertical force. We also measure this force by the *change of momentum* it produces in that vertical direction in the unit of time.

It is to be carefully observed that the law applies equally to bodies at rest and to bodies possessing any kind of motion; for the same amount of change will always be produced by the same force, whatever forces or motions may be already in operation on the body, and whether the change conspire with or oppose any motion already possessed.

In other words, whatever number of forces be acting on a body, each force may be regarded as producing independently its own change of motion; so that the resulting force must be in the direction and in the proportion of the resulting change of motion, and may thus be found from a consideration of the motions solely. This we have already anticipated in explaining how the rule of the *parallelogram of forces* reduces itself practically to that of the *parallelogram of motions.*

166. Further, this second law is the ground of our measurement of force, as well as of mass.

By the definition of force, different forces acting on the same body for the same length of time will produce in them velocities proportional to those forces; and so we have the means of comparing forces by the velocities they generate per second in the same mass.

Thus, two boys compare their force of muscle by trying how far each will roll the same stone or ball along the ground, the distances being proportioned to the velocities in this instance.

In this way we compare the force of gravity at different parts of the earth's surface, by its accelerating power on the same body carried from place to place.

Again, the same force acting on different masses will produce velocities which diminish in proportion as the masses increase.

With the same exertion a soldier will roll a ten-pound cannon ball twice as far as a twenty-pound ball; and the same charge of gunpowder will send the latter ball only half as far in a horizontal line as the former.

Lastly, if the force be changed and the mass it moves be changed, and yet the velocity remain unchanged, it is manifest that the force and the mass go hand in hand in their changes, or the force is proportioned to the mass. This, we have seen, is illustrated by the case of gravity acting on bodies falling freely; all bodies require the same velocity in the same time under the attractive power of the earth, and hence this force must be proportioned to the mass.

167. There is no action or motion in the universe but at the expense of an unequal and opposite concomitant action: or, as it is usually quoted, "*Action and reaction are equal and opposite.*

If a man in one boat pull at a rope attached to another boat, the two will approach. If they be equal in size and load, they will both move at the same rate in whichever the man may be; if unequal, the lesser mass will move the faster. With the rope attached to a large ship, the man's boat alone would seem to move; yet he really moves the ship a little; only if the ship be a thousand times as heavy as the boat, its motion will be but a thousandth part of that of the boat, and it would require a thousand men in a thousand boats pulling all together to make the ship meet them half way.

A magnet and a piece of iron attract each other equally, whatever disproportion there is between the masses. If either be balanced in a scale, and the other be then brought within a certain distance beneath it, the very same counterpoise will be required to prevent their approach, whichever be in the scale. If the two were hanging near each other as pendulums, they would approach and perhaps meet; but the smaller mass would perform the greater portion of the journey.

So a pound of lead and the earth attract each other with equal force; but that force makes the lead approach sixteen feet in a second towards the earth, while the contrary motion is as much less than this, as the earth is heavier than one pound, and is, therefore, utterly inappreciable.

The attraction of the earth and moon is mutual: but, as the earth is much the larger body, the attraction alters the motion of the moon far more than it does that of the earth; still, just as a boy, holding on by a man's coat, draws the coat away from the man to a certain extent by his reaction, though he may be compelled to move with the man, so the reacting force of the moon draws towards it the waters of the ocean—the loose jacket of the earth as it were—and so exhibits in the phenomenon of the *tides* the mutual character of the attraction.

168. A cannon, when fired, recoils with even greater force than the momentum given to the ball, for it suffers the reaction of the expelled gunpowder as well as of the ball; but the large mass of the cannon diffuses the reacting momentum and gives a small velocity, which is rapidly checked by the friction between the gun-carriage and the ground. Were the cannon fired from a balloon, however, the reaction would be more marked.

The recoil of a light fowling-piece may hurt the shoulder, unless the piece be held close to it so as to form one mass with the body.

A ship in chase, by firing her bow-guns retards her motion; by firing from her stern she quickens it.

A ship firing a broadside heels or inclines to the opposite side.

A vessel of water suspended by a cord hangs perpendicularly; but if a hole be opened in one side the vessel will be pushed to the other side by the reaction of the jet, and will so remain while it flows. If the hole and jet be oblique, the vessel will constantly turn round in the direction opposite to the flow of the water.

A vessel of water placed upon a floating piece of plank, and allowed to throw out a jet, as in the last case, moves the plank in the opposite direction.

A steamboat may be driven by making the engine pump or squirt water from the stern, instead of making it, as usual, move paddle-wheels. There is a great waste of power, however, in this mode of applying force, as will be explained under "Hydraulics."

The propelling force in rowing, in swimming, or in the motion of a steamer, is just equal and contrary to the force with which the water is pushed backwards.

The upward motion of a bird in flying is equal and opposite to the momentum with which its wings strike the air.

A sky-rocket, in like manner, ascends from the reaction of the force with which the exploding gas pushes against the air.

169. A bent spring, allowed to unbend between two masses, pushes both apart with equal force; only the greater the difference in the amounts of the masses, the greater will be the difference of velocity produced by this mutual action. If the one mass be very small compared with the other, the small one alone will seem to be repelled, and the other will appear merely to *resist* the motion.

Similar to this is the case of a person jumping up or throwing up a stone; his secret power of exerting force is like that of the bent spring, only of a more hidden and complex character: and the effort which projects either the stone or the person himself, throws the earth backwards, though imperceptibly.

So when a horse drags a boat on a canal, the force with which the boat moves is at the same instant communicated, through the frictional connection between the horse and the ground, to the earth in a backward push of equal amount. If the horse were moving on ice, and the friction insufficient to connect the horse and the earth as one mass for the instant, then in attempting to pull a heavy boat the horse would move backwards himself faster than the boat would move forwards.

A man pushing against the ground with a stick may be considered to be compressing a spring between the earth and the end of his stick, which spring is therefore pushing him up as much as he pushes down; and if, at the time, he were balanced in the scale of a weighing beam, he would find that he weighed just as much less as he pressed down with his stick.

170. The truth of this law is well shown by the impact or concussion of elastic balls—as those made of ivory or glass.

When one billiard-ball strikes directly another ball of equal size it stops, and the second ball proceeds with the whole velocity which the first had—the action which imparts the new motion being equal to the reaction which destroys the old. Although the transference of motion, in such a case, seems to be instantaneous, the change is really progressive, and as follows. The approaching ball, at a certain point of time, has just given half of its motion to the other equal ball, and if both were of soft clay, they would then proceed in contact with half the original velocity; but, as they are elastic, the touching parts at the moment supposed are compressed like a spring between the balls, and by then expanding and exerting force equally both ways, they double the velocity of the foremost ball, and destroy altogether the motion of the one behind.

If a billiard-ball be propelled against the nearest one of a row of similar balls in contact, it comes to rest as in the case last described, while the farthest ball of the row darts off with its velocity—the intermediate balls having each received and transmitted the motion in an instant, without appearing themselves to move.

171. If there be no external matter to react upon there can be no change in the state of a body's motion. A person suspended in mid-air would be quite powerless to move through space, because he would have no matter outside of himself to push against.

This may be well illustrated by a simple experiment represented in figure 16. Suspend two similar billiard-balls by two strings of the same length from a cord stretched tight across a room or between two chairs. If now the ball, A, be made to swing *along* the direction of the cord, C D, it will keep on swinging, because it can give up none of its motion to B in that direction. If, however, it be made to move *across* the line of the cord, C D, it causes the cord to vibrate, and gradually sets B vibrating too. But A cannot cause B to move without itself losing an equal motion. Thus, while B swings wider and wider, A is slowly brought to dead rest; and the state of matters just begins to be reversed, B giving up its motion to A and gradually stopping, till the situation is precisely the same as at the beginning of the experiment; this alternation of motion would go on long enough, were it not that the friction of the air gradually exhausts the whole of the motion, and brings both to rest.

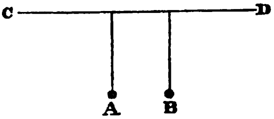

Fig. 16.

So, if both balls be suspended from the same point, and if one ball hang at rest while the other is made to circle round it, the first will, by the twisting of the thread, be gradually set in motion, while the second is brought for a moment to dead rest in the centre of the circle described by the first.

It is the same in whatever way the motion is communicated; whether it be by gravity, or by the momentum of visible matter, or by the more secret forms of magnetism and electricity, the law of action and reaction is invariable. For instance, we may substitute two straight magnets for the balls in last experiment, and place them so as to have their like ends—say the two north poles—towards each other. If then we leave B at rest, and make the other swing, so that its north end comes near the north end of B, the two will repel each other, and B will begin gradually to swing too; but A is at the same time gradually brought to rest by the reaction of B on it. When A is brought to a dead halt, B begins to give A motion again at the expense of its own, and so they will continue to take and give their motions until the resistance of the air brings both to rest.

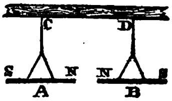

Fig. 17.

Again, if we turn one of the magnets round so that the unlike or attracting ends face each other, the force spent by the vibrating magnet, A, in pulling B towards it, is lost to A itself; so that, while B is made to vibrate, A comes gradually to rest as before.

Such are but a few of the illustrations that might be given to show that, in every case of mutual action between two bodies, whether it be one of attraction or of repulsion, there is a simultaneous equal and opposite action produced: or, in other words, that *the sum of the momenta in any two bodies remains unaltered by any mutual action between them.*

"THE PRINCIPLE OF ENERGY."

172. These three laws are subservient to one grand general principle which had not been conceived in the days of Newton, nor till long afterwards, a principle having for its fundamental axiom that the absolute creation and absolute destruction of force are alike impossible within the range of our experience. It is known as the law of *Energy*, and a clear conception of it is at the bottom of all knowledge of modern Physics.

"*Energy.*"

173. A man is said to have great bodily *energy* when he is capable of overcoming many obstacles, or of getting through a great amount of labour or *work*. His work is the measure of his energy, and the translation of it into a visible form.

The blacksmith who shoes two horses while his rival shoes only one is said to exert double the energy of the other.

If a man and a horse be employed separately to raise coals from a mine, the horse will raise perhaps ten times as many as the man in the same time; he is thus said to possess ten times the energy or work-power of a man.

Again, a steam-engine might raise ten times as many coals as the horse can do; and, though inanimate, may in respect of its work-power be compared with a horse or a man.

These terms—energy and work—are employed in like manner in speaking of the power of a moving body to overcome any resistance—such as that of the air, or of gravity, or of a magnet, or of a spring, &c. Only they are used with a more definite meaning, inasmuch as the actions of inanimate matter are susceptible of more exact comparison and measurement than those of living beings.

A man's energy or power of doing work will vary from day to day—even from hour to hour—according to the state of his body, and often in a manner which there is no accounting for, owing to the complexity of the animal machine.

On the other hand, the penetrating power of a 50-lb. cannon ball projected with a given weight of a given kind of gunpowder may be calculated with exactness.

174. In mechanics, then, *Energy is the power of effecting work; and Work is the overcoming of resistance of any sort.*

A bullet that just pierces through 300 leaves of a book has been projected with triple the Energy of one that can pierce only 100 of these leaves; and if the former would reach 600 feet shot vertically up, the latter would reach only 200 feet.

The strength or energy of a man's arm is often measured by the extent to which he can overcome the elasticity of a spring either by a fair pull, or by a blow.

" *The principle of the measure of Work.*"

175. For the precise estimate of the amount of Work-power in any moving mass, we must agree on some definable amount of resistance offered to some definite quantity of matter or mass; and we might select for this purpose any constant and reliable resistance.

On seeking for a standard of measure among the various resistances that have to be overcome, such as the resistance of the air, or of water, the friction of sliding bodies, cohesion, as in a steel spring, magnetism, electricity, gravity, we find that none of them is so simple, so constant, and so easy of employment as gravity.

The resistance of the air is variable, because its weight depends on its temperature, which is very far from constant. We might, if we chose, select the resistance of water to, say, a square foot of plate moving at a given rate as a standard of comparison for the measureing of Work; but practically this would be inconvenient. Again, the friction between rubbing surfaces depends so much on the variable condition of smoothness that this would be equally unsuitable as a standard of reference. Magnetism and electricity are qualities more or less transitory, and are on that ground unfit for our purpose. Lastly, the resistance offered by the elasticity of a spring, or of a piece of india-rubber, or of a column of air, is dependent on a minute molecular condition which we have no certain means of gauging, and is therefore unavailable as an absolute and ultimate representative of Work.

On the other hand, the resistance which the earth offers to the lifting of a given mass is invariable at the same spot on the globe, and is withal so convenient, that it is greatly preferable to any other standard.

The same amount of Work-power was needed to raise the huge pile of the pyramids in olden times, by whatever means it may have been supplied, as would be required at the present day; though, by unskiful mechanical contrivances, much more Energy may have been spent in those days in motions not conducing to the direct elevation of the masses.

Thus, then, if we have a definite quantity of matter which we can depend on being able always to measure, and if we have a definite standard, or unit, of length or distance which we can also be sure of ascertaining at any time, we are certain that the force, or Energy, or Work-power required to raise this mass vertically from the earth through this distance is unchangeable at the same spot on the globe, and may, therefore, be chosen as a standard of reference.

" *The Foot-Pound, or British Unit of Work.*"

176. The quantity of matter that we call a pound (in London), and the space that we call a foot, are measures now so well known, and so often recorded over the world, that nothing short of the destruction of our race would prevent them from being at any time recovered as standards of measurement.

> *The unit of Work* is accordingly defined as *the Energy required to raise one pound of matter of any sort vertically through the space of one foot at London*, and this is known as the FOOT-POUND or unit of Work in this country.

" *The Kilogrammetre, or French Unit of Work.*"

177. The French have different units of measure which they call the *metre*, and the *kilogramme;* the former is about a twelfth part longer than the English yard; or, more exactly, the *metre* is 39·37 inches, that is, 12 metres go to make nearly 13⅛ English yards; and the kilogramme is a little over two pounds avoirdupois; or, more exactly, 15,432·35 English grains. In France, then, the unit of work is defined as the *Energy required to raise a kilogramme through the space of a metre*, and this is called the *Kilogrammetre.* It is about 7¼ (or 7·233) times greater than the foot-pound, and may sometimes be more convenient in stating large amounts of Energy.

" *The practical measure of Work.*"

178. Work, as we have defined it, must depend on two things for its measurement: (1.) on the *weight* raised; and, (2.) on the ***height***

to which it is raised. If we have got to raise five books, each weighing a pound, through five feet, it will obviously require the same amount of Energy to raise the whole at once to this height, as to raise the books singly a foot at a time : that is, the work done in this case is equal to twenty-five foot-pounds. Hence the simple rule :—

The whole weight raised in pounds, multiplied by the whole vertical height in feet, gives the amount of Work done against the resistance of gravity in foot-pounds. Or, on the French scale,

The whole weight in kilogrammes, multiplied by the whole vertical distance in metres, gives the Work measure in kilogram-metres.

A steam-crane raising a hundred-weight of goods from the hold of a ship up to the deck or the quay, say a distance of twenty feet, does 20 times 112, or 2240 foot-pounds of Work, the same amount as if it raised a ton through the space of one foot.

" *Connection between Work-power and Velocity of a moving body.*"

179. A railway train going with double velocity possesses double quantity of motion, momentum, or shock-giving power; but its Energy or power of overcoming resistance is more than doubled. It will go on not *twice* but *four* times as far as when its velocity is only half what it is.

A rifle ball shot vertically up with a velocity of 120 feet a second will reach not three times but nine times as far as with a velocity of forty feet a second.

A steamer going along at ten knots an hour will, after the steam is turned off, and the motion is left to the friction of the water to subdue, go on for twenty-five times the space that it would go if it had a speed of only two knots.

A cannon ball sent out with a velocity of 100 feet a second, will penetrate not *twice* but *four* times as far into an earthwork or sand-bank as with a velocity of 50 feet a second; or it will pierce through four planks of wood in the first case, and one plank in the second.

Thus penetrating power, Work-power, power of overcoming resistance, or Energy, increases at the square of the rate at which the velocity increases.

And the reason is obvious when we consider that the Energy acquired in falling through any space under the influence of gravity is necessarily identical with the Energy subtracted from a moving body by the same force of gravity during the same space. The one case is merely the obverse of the other. Now, we have seen that in order to double the velocity acquired by a stone falling through ten feet, we must let it fall through forty feet; in order to triple the velocity we must let it fall through ninety feet; in other words, that the spaces passed over under the accelerating force of gravity increase at the square of the rate that the velocity increases. Consequently, the energy or power of passing over space against gravity or any uniform resistance, is proportioned to the square of the velocity possessed by the moving mass.

180. Of course, if the force of resistance be more intense than that of gravity, shorter time and space will be required for it to produce the same amount of work or change of energy.

The work-power generated in a heavy hammer-head by the force of gravity drawing it through a space of a few feet, is equivalent to that of the force of friction against the small mass of a nail acting only through perhaps half an inch.

Pile-driving illustrates the same fact.

181. The following instances are explained by the fact, that the Energy or power of overcoming resistance increases at a greater rate than the bare velocity :—

A door standing open would yield readily to the gentle push of a finger, yet is not moved by a cannon-ball shot swiftly through it, because the force of cohesion between the molecules of wood is not strong enough to produce, within the limit of fracture, energy sufficient to overcome that of the flying ball. The cohesion of the circle cut out in the door by the ball might resist more than a hundred pounds laid quietly upon it; but, supposing the bullet to fly 1200 feet in a second, and the cohesion to be destroyed one-tenth of an inch, it would require to be strong enough to destroy in the 144,000th part of a second the moving force of the heavy mass, a task to which it is wholly unequal.

So a leaden bullet, pressed slowly against a pane of glass, breaks it irregularly, where the strength happens to be least, but shot at it from a pistol, makes a clean, round hole. It has been amusingly explained, that the particles struck and carried away have not had time to warn their neighbours of what was happening.

Thus, too, a cannon-ball, having very great velocity, passes clean through a ship's side; while one with less speed splinters and breaks the wood to a considerable distance around. A near shot thus often injures a ship less than a more distant or a weaker one.

A sheet of paper bent to stand edgeways on a table, may not be driven down by a pistol-ball fired through it.

This explains, with respect to gun-shot wounds, why a person often remains ignorant for a time of his misfortune, and why a rapid bullet kills only the part which it touches, while a spent ball may bruise and injure widely around. In many cases of injury, popularly attributed to the *wind of a ball*, the ball has really touched the part.

A circular plate of soft iron, rotated with extreme rapidity will cut through a stone, or even the hardest steel file, almost as a knife cuts through a carrot. In cases where a soft powder spread on the rim of a wheel suffices to polish a hard body, it acts partly like this plate, by the motion or velocity given to the wearing particles.

Fine sand or emery projected from a tube by steam with a very high velocity, will pierce a hole in stone or metal, or even glass; and this fact has been recently turned to useful account in the arts of stone cutting and engraving.

That penetrating or work-power depends on velocity more than on mere momentum, is shown by the comparatively insignificant effect of the recoil of a cannon or rifle, though in momentum it is equal to that of the ball.

Paradoxical, then, though it may appear at first sight, it is an important truth that of two bodies moving with equal momenta, the one which has the higher velocity and the less mass will have the greater Energy. The result of a large number of experiments has shown that the penetrating power of a rifle ball is much increased by reducing the weight of the ball and increasing its velocity.

"*Different Forms of Energy.*"

182. It is in many cases very advantageous to regard the different so-called forces of nature, some of which we have already considered, as but so many *forms of Energy*, or sources of Work-power. By denominating them Energy rather than force, we imply that they may all be referred to some common standard of comparison, and thus make one step towards that assimilation of the various agencies around us, which is the crowning glory of modern science.

These forms of Energy, then, may be thus enumerated:

(1.) *Gravitation*, or *Molar Attraction*, one of the most apparent, and one of the most important forms of Energy, because it is all-pervading. That bodies falling under the attraction of the earth have a power of combating resistance, scarcely needs illustration.

Mills driven by falling water, clocks and other machines driven by falling weights, pile-engines, tilt-hammers, &c., all make use of this form of Energy.

(2.) *Cohesion*, or *Molecular Attraction*, the form of Energy exhibited in springs and elastic substances—such as india-rubber. The bow, the boy's catapult, the mainspring of a watch, exemplify the work-power of this nature. The apparently passive exhibition of power to resist separation of the particles of a body is really this form of Energy, and a most valuable one it is; rigidity entering as an essential element or factor into all pieces of machinery.

(3.) *Chemical Attraction*, or *Atomic Energy*, a widespread agency in the world about us, most familiarly exhibited in the collapse or falling together of oxygen and carbon atoms, which constitutes the all-powerful action of burning.

(4.) *Heat* is a most potent form of Energy. It is from our coal-fields, through their heat-producing power, that we obtain nearly all the mechanical power of the present day.

(5.) *Magnetism*, as shown by the action of the earth on the mariner's compass; by a piece of steel which has been treated in a certain way; and by the electric or galvanic current when it is made to pass in a spiral wire, as will be afterwards explained.

(6.) *Electricity*. By rubbing a stick of sealing wax or a rod of glass with a silk cloth, we produce in the stick or rod a curious power of lifting small bodies from a short distance, against the force of gravity. So in the galvanic battery, to be afterwards explained, we have a more obedient and docile form of this same electric Energy, by means of which, at the beck of a person's finger in London, a little arm may be pulled to one side or the other at Edinburgh, just as surely as if the person pulled a frictionless string.

(7.) *Light* is a still more impalpable and immeasurable form of Energy. That it is a motion or vibration of an ethereal fluid filling all space, is now very generally believed. Though the Work it if capable of doing, and the effects it produces on sensible matter, have as yet utterly baffled calculation, there can be no question but they are equally real with those of the other forms mentioned above.

(8.) *Vitality*, or *Animal Energy*, is the most mysterious and elusive form of all.

"*Two conditions of all forms of Energy, the* KINETIC *and the* POTENTIAL."

183. All these forms of Energy may exist in one or other of two conditions, the one an *active*, *motive*, or *obvious* condition, the other a *passive*, *dormant*, or *latent* condition. In order to prevent misconception, the specific terms *kinetic* and *potential* are respectively applied to these two conditions of Energy, the former being derived from a Greek word meaning *motive*, and the latter from a Latin word meaning *possible*.

Gravitation offers the most simple illustration of these two conditions. A stone falling from a height, a stream of water running —that is falling slowly from a height, a hammer-head descending, all obviously possess active, actual, or kinetic Energy; for they are capable of overcoming resistance in virtue of their mass in motion. On the other hand, a stone lodged on the face of a mountain, a clock-weight wound up, a head of water pent up in a cistern, though all actually at rest, possess, *in virtue of the very position of their masses relatively to the earth*, a dormant, possible, or potential Energy which we may at any moment convert into actual. The one is as real as the other, and the one represents, and has been called into existence at the expense of, a *definite amount* of the other. We cannot have actual motive Energy under gravity from a body lying on the ground, or from a clock-weight run down; it must have been raised to a height first, and have possessed the possible or potential Energy. And when we do have it, it is merely the restoration of the *actual* Energy which had been expended in raising the mass to a height. Thus, the Energy of a clock-weight shown in moving the machinery for the space of a week, is merely the doling out of the potential Energy imparted to it in a few seconds in winding up.

When, therefore, we throw up a stone, the kinetic or actual motive Energy which it possesses at starting is gradually exchanged for the potential or possible Energy of position, until at last the transference is complete, the motion ceases, and the Energy is solely potential. When the body begins to fall again, we have the circumstances reversed, and a gradual conversion of the Energy of position into Energy of action.

184. **The *pendulum* is the simplest and best illustration of the two conditions of Energy and of their mutual equivalence and exchangeability.**

Any mass suspended by a wire or cord so that it can swing freely backwards and forwards is called a pendulum. When a leaden bullet hangs by a silk cord at rest in a vertical position, as *p a*, it possesses no Energy at all as a pendulum; but when we move it to one side, *b*, we raise it through the space, *a h*, and endow it with a potential Energy, which is ready to be converted into actual or kinetic whenever we choose to let it drop. Its Energy on arriving at *a* is all kinetic, and the exact equivalent of that imparted in raising it at first: this carries it on towards the other side, *c*, till it reaches a height exactly the same as that of *b*, where its Energy is once again potential only, and the same as at *b*. Thus, if we neglect the impediments of air and friction, the Energy which we imparted at first to the pendulum will continue to oscillate between the extremes of *all potential* and *all kinetic*; but at every instant the *total Energy* will remain the same as at first if we suppose the interference of the air and of friction removed.

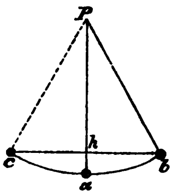

Fig. 18.

185. We have an exactly corresponding case, though on a microscopic scale, in the vibrations of an elastic body through the Energy of molecular attraction or cohesion.

The separation of molecules within the limit of cohesion resembles the lifting of a weight, and is the transformation of actual or kinetic Energy of some sort into *potential Energy in virtue of molecular position*. Thus the winding up of the mainspring of a watch is exactly similar to the winding up of a clock-weight. The starting of the balance-wheel in the one case, just like the starting of the pendulum in the other, allows the potential Energy to fall down, as it were, by a succession of steps into actual or kinetic Energy, each descent lasting but a small fraction of a second.

When a boy holds his catapult stretched, he has separated the molecules of the india-rubber, and obtained by the muscular power of his arm their Energy of cohesion in the potential condition, ready to pass into the kinetic when a sufficient temptation offers.

So in a stretched bow we have the Energy of the arm stored up in a convenient potential form.

186. Chemical or atomic Energy may exist in either of these two conditions, and though the individual masses in which it is resident are utterly invisible, we can picture the difference of condition in a general way. In the actual or kinetic state, chemical Energy is possessed of enormous power, as is seen in the extraordinary development of heat and light by the explosion of gunpowder, or the yet more terrific nitro-glycerine. Energy, as we know, depends on the mass and the *square of the velocity* conjointly; thus, though atoms are of the extreme minuteness which we have already considered in the first section, still it is not beyond conception that, with a correspondingly great velocity, millions of them together should possess the enormous Energy exhibited in the effects of chemical combination.

" *The two conditions of Chemical Energy.*"

187. In gunpowder we have the Energy of the chemical elements stored up in the statical or potential condition; and, like a lake on the top of a mountain confined by sandbanks, it is ready to burst forth in a kinetic torrent, whenever the feeble barrier is broken.

So the gases oxygen and hydrogen, mixed in the proportion of one to two by bulk, possess great chemical Energy in the dormant state; the mere application of a taper flame, or the mere passage of an electric spark, is sufficient to start a mutual combination or *fall*, possessed of the most terrible power, as has been seen in the accidental explosion of the oxygen and hydrogen gases when kept in the mixed condition for use with the lime-light.

Water, as we have stated already, consists of these two gases, and, by the application of kinetic Energy in the form either of heat or of electricity, we are able to overcome their powerful chemical attraction and obtain them in the separate state. The chemical Energy thus stored up, which we can make manifest by the mere application of a light, is the exact equivalent of that by which their separation was effected, just as the Energy reproduced by a falling body represents the exact amount expended in raising the body.

> Chemical separation, then, or atomic separation against chemical attraction, corresponds exactly to molar separation from the earth against the force of gravity.

In coal, we have another and most remarkable example of potential chemical Energy, stored up in former ages by the power of the sun. Plants and vegetables grow, or collect their substance, out of the carbonic acid gas which forms one of the constituents of the atmosphere. The sun's heat and light enable the vegetables to separate the carbon from the oxygen of the carbonic acid gas, and coal is but this solid carbon of the vegetable growths of former ages dried and compressed under the weight of superincumbent strata. Thus we have in coal a store of the carbon, extracted in bygone ages by the Energy of the sun from the atmosphere, ready to unite again with the oxygen from which it has been parted so long; and, in burning, we have but the restoration to an active form of the Energy or Work-power so stored up by the sun in former geological epochs.

"*Heat Energy may exist in two conditions.*"

188. Heat, which was at one time regarded as some subtle kind of matter, is now universally acknowledged to be but a special condition of molecular Energy, closely allied to the two last-mentioned conditions. In the kinetic, sensible, or appreciable state, it is merely a minute quiver or vibration of the molecules and atoms of bodies; many millions of these invisible motions combining to produce motions of larger and visible masses, as is notably exemplified in the steam-engine, whose motion is but the manifestation of the united impulses of countless numbers of the invisible particles of steam.

But kinetic or actual heat-energy may also pass into the stored or potential condition, and exist as a *molecular arrangement* or separation capable of being recovered on the return of the particles to their original situation. Thus, in melting one pound of ice, kinetic heat-energy, sufficient to increase the molecular excitement of one pound of water through 143° Fahr., will be expended in merely producing the liquid arrangement of the particles, without altering the sensible amount of warmth.

So, one pound of water, at the boiling point, will require as much kinetic energy to be expended in separating the molecules into the form of steam as would raise it through 967° Fahr., or 967 pounds through 1° Fahr., and yet the steam *appears* no hotter than the boiling water.

Water at the freezing point has, however, *really* more heat-energy than ice, for the heat expended in liquefying it *reappears* when it returns to the solid state; and steam is *really* hotter than water at the same *apparent* temperature, the extra heat being made manifest only when the steam falls together or condenses again.

In every case when a heated body collapses or contracts by cooling, the actual heat-energy, which had been expended in swelling it out, is entirely recovered as *sensible* warmth; and, according to some philosophers of the present day, this is sufficient to keep up undiminished for thousands of years the present temperature of our sun, on the supposition that it is a white hot ball in a state of contraction.

189. In the case of the other and more mysterious forces of nature which we have enumerated above, viz., electricity, magnetism, and light, we cannot, at this early part of the volume, exemplify the distinction of the two conditions of potential and kinetic. This must be deferred till the nature of the forces has been explained; but it may be stated that the same difference of condition is manifested in them; there being, for instance, an electrical Energy of motion and an electrical Energy of mere separation or position.

Mutual connection of Energies.

190. The common designation "Energy" is applied to all these forces, because there is such a close connection between them that any one energy may be remoulded and brought out in the form of any other.

Mechanical Energy, or the motion of visible masses, may be turned into heat, electricity, magnetism, or even light; and the disappearance of Energy in any form, is simply its conversion into some other invisible form.

When the rifle-ball hits a target, the Energy of projection is by no means lost; it is merely transferred to the molecules and atoms of the ball and of the target in the shape of an invisible heat-quiver. The roaring violence of the foaming cataract spends itself in heating the rock on which it strikes, as well as in heating the particles of the water.

Impact is thus one of the means whereby energy in a visible and tangible shape is rendered invisible and intangible. Men are no longer satisfied with the statement that when the hammer strikes the anvil, its moving force is stopped, disappears, and seems to be lost. The mind is able to follow the motion farther, and to see it transmitted to the minute particles of the anvil, and really existing there in a state, invisible, indeed, yet capable of detection by a thermometer or other such instrument.

191. When impact takes place between *perfectly elastic* bodies, which is nearly realized in the impinging of polished ivory or glass balls, there is an oscillation of the molar Energy of the ball somewhat analogous to that of the pendulum. If such a ball be dropped on a surface of the same material, the sensible or molar Energy acquired by the fall disappears for a moment, being converted into a potential energy of position against the force of cohesion among the particles; as with the pendulum at the turning point of its arc of vibration, there is a moment of pause, after which the cohesive attraction restores the former actual or visible Energy in a contrary direction, and the ball rebounds at the same rate at which it fell.

Were there no air and no friction to impede the swing of a pendulum, and cause its visible Energy to pass into heat-motion, we know that it would go on oscillating for ever. As it is, the returning velocity is always less than the advancing one. So in reality we find no body perfectly elastic; there is always more or less conversion of the impinging Energy into heat-vibration between the particles, and therefore never complete restoration of the impact by the force of cohesion. There is loss of visible Energy and production of this heat-motion in proportion as the body is inelastic; but there is no *annihilation* of Energy.

Friction is but the transferring, through impact of surface protuberances, of visible or molar energy into molecular or invisible heat-vibration. If it be sufficiently continued, the minute quiver of heat may rise to such a degree that it again becomes visible, as when the brake of a railway train is heated until it catches fire.

The motive power of a flowing river may be converted into useful work by turning a hundred mills in its course, or it may all be allowed to run to waste in the shape of friction against its bed, diffusing an invisible quiver throughout its own particles and those of the earth against which it rubs.

So, could we utilize the ceaseless surge of the ocean, it would be a powerful source of Energy; as it is, it is allowed to be expended merely in heating the ocean waters and the rocks on which they lash.

The penetrating power of the cannon or musket ball is but the combined atomic energy of the gunpowder, set loose by the application of a spark, just as a huge boulder on the face of a rock may have its Energy of position transformed by the removal of a trifling obstacle.

Nor is this connection between different kinds and forms of Energy a mere vague assertion of cause and effect. Not only is the chemical Energy the cause of the projectile force of the ball, but the mechanical force of the ball is really the identical chemical Energy in another form.

A railway train is stopped, as we know, by the application of the brake and by friction against the rails; but the heat developed by friction is not a mere invariable accompaniment of the stoppage of the train, for it is the actual motive Energy transformed into another shape, just as the original momentum of the train was the heat-motion derived from that of the steam (derived in its turn from the oxidation of the carbon in the coal, that again being derived from the primeval energy of the sun); and, could we recover or measure exactly all the heat generated by friction in the stoppage of the train, we should have exactly the same amount as that expended in setting it in motion.

192. Some general ideas on the subject of this mutual relation between forces or Energies had been long entertained before any definite facts had been established. By the labours of our countrymen, Joule and Thomson, as well as by those of several continental philosophers, an *exact numerical relation or equivalence* was proved to exist between the amount of heat produced by friction and the amount of mechanical force expended in producing it. And this establishment of the *Mechanical Equivalent of Heat*, as it is termed, was the first experimental step towards the modern doctrine of Energy.

By a series of ingenious and careful experiments, Joule succeeded in establishing that the force resulting from the fall under gravity of one pound of matter through the space of 772 feet is just sufficient to heat one pound of water by the amount of 1° Fahr., if converted by impact or other means entirely into heat. That is to say, the molar motion of one pound, generated by this extent of fall, is converted into an intensely rapid quiver of the molecules of the water, which we measure by saying it raises one pound of water by one degree of Fahrenheit's scale.

Thus, 772 foot-pounds is denominated the *mechanical equivalent* of heat.

Between the other forms of Energy—such as Heat and Chemical or Electrical Force—similar definite correlations have also to some extent been established; but the practical determination of them is much complicated through the impossibility of insuring the conditions that Energy may pass from one form into another pure and simple—such as electricity only into heat only—and the detecting and measuring of all the forms of Energy simultaneously produced, is the problem that has to be solved before such correlations can be fully and absolutely asserted.

Conservation of Energy.

193. The conclusions from these experiments have been carried one step farther. They have shown that not only may one kind or form of Energy be translated into another, but also that in the translation nothing is lost, and that there is every reason to believe that the destruction of Energy is, equally with that of matter, impossible. There is, throughout the universe, nothing but the *transformation of Energies;* no loss of Energy is possible. Its disappearance in one form is owing to its change or conversion into another; and had we a machine or engine capable of reversion like the simple pendulum, for kinetic and potential Energy, we might see the oscillation of Energy between the two forms of mechanical and heat Energy, for example, just as we do that of the pendulum between kinetic and potential.

There may be an ebb and flow between the relative amounts of the various Energies, but the sum of them all is constant and invariable throughout our universe. There may, indeed, be a tendency of all the present Energies of nature ultimately to pass into one uniformly diffused heat-quiver: it may be indeed that, in some incalculably remote age, all the changes will have been rung upon the present distribution of the forms of Energy, and that the vitality of all nature will exist merely as a universal pulse. Yet the grand generalization of modern times constrains us to believe that in that pulse will be found the exact representative of every motion and form of Energy at present operating around or within us, that, in fact, Energy is coeternal with matter. We cannot say that we know fully the nature of the different Energies—such as magnetism, heat, electricity, and chemical affinity; but the principle of the Conservation of Energy, with which alone the facts discovered by modern experiment appear reconcilable, justifies us in regarding them all either as some species of actual motion, or as some sort of potential Energy inherent in definite arrangements of those minute particles which form the foundation of the material universe.

PART II.

SECTION I.—CENTRE OF GRAVITY.

ANALYSIS OF THE SECTION.

As the earth's attraction, acting equally all round its centre, has a resultant or combined effect radiating from that centre, so the conjoint effects of the weight or gravitation towards the earth of all the particles of any body balance about a point within the body, which is known as the CENTRE OF GRAVITY. *The situation of this point, in a body of uniformly distributed mass, may be determined by calculation from its figure; and, in bodies of regular shape, is identical with the* centre of the figure. *In bodies of irregular shape or distribution of mass, its position may often be found most readily by experiment. It is of great importance to consider the effect of the position of the centre of gravity in bodies and structures relatively to their supporting bases; as the conditions of* stability *or* instability *depend upon this relative position.*

The centre of gravity is also the CENTRE OF ACTION *of any force distributed uniformly, as gravity is, through any mass.*

"CENTRE OF GRAVITY."

194. If a uniform beam or rod be supported by its middle, like a weighing beam, the two ends will balance each other, because there is just as much similarly situated matter on the one side of the support as on the other, and therefore no reason why the attraction of the matter on one side should overpower that on the other. If equal weights be afterwards placed in corresponding situations on the two arms of the beam, the balance will not thereby be disturbed; and the operation of adding weights that counterpoise, above and below, and near and far from the centre, may be continued, until a bulky mass is built up upon the beam, yet the whole will remain perfectly supported and in equilibrium about the original centre. Now, in every body or mass, or system of connected masses, there is a point of this kind about which the weights of all the parts balance or have equilibrium, and it is this point which is called the *centre of gravity*. Although in any mass, therefore, every atom has its separate gravity, and the weight of the body is really diffused through the whole, still, by supporting this one point either from above or from below, the whole mass is equally supported if the body be a solid or rigid one ; by lifting it, the whole is lifted ; by stopping it, the whole is brought to rest ; and when it rises or falls, the general mass is really rising or falling. Thus for many purposes the weight of a body, however large, may be considered as concentrated in its centre of gravity.

195. In more precise language, the centre of gravity is *the point of application of the resultant of the weights of all the elementary particles of which a body consists*, which, for masses of ordinary magnitudes, may be regarded as a series of parallel forces.

Thus the centre of gravity is the centre of a series of parallel forces, and may, like the centre of parallel forces, be found from purely abstract or geometrical considerations.

In a mass of regular shape and of uniform substance, as a ball or a cube of metal, this point is evidently the centre of form ; but in bodies that are irregular as to form or distribution of density, the calculation of its position is more troublesome, and in some cases impossible. By the following simple experimental method, however, this centre may often readily be found.

196. Since the centre of gravity is the point about which the weights of its various parts balance, it is clear that it must be vertically under, and in the same line with, a cord by which the body is suspended so as to balance.

Thus if an irregular piece of plank or of pasteboard, represented by *a e b d* (fig. 19), be suspended by a cord from any point, as *a*, and the cord of a plummet, *a g*, be attached at the same point, the cord of suspension and the cord of the plummet will be in one line, and the centre of gravity of the board must be somewhere in the line of the plummet, which we can mark on the board. If it be then suspended by another point, as *d*, and the new direction of the plummet line, *d e*, be marked, the point *c*, where the two lines cross, will indicate the centre of gravity ; and the board, when supported by a cord attached there, or on a point placed there, will remain evenly balanced.

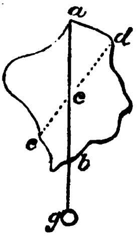

Fig. 19.

"Centres of gravity of bodies of uniform density."

197. It is often useful to know the centre of figure, which is also the centre of gravity in uniform bodies of that figure; we therefore give a few of the more common cases which may be determined either by pure calculation or by trial.

The centre of gravity (or figure) of a uniform *straight rod* is at its *middle point*; of a *circular area* or *ring* is at the *centre* of the circumference; of a *rectangle* or of *any parallelogram* is at the *crossing of the two diagonals*; of a *ball or sphere*, hollow or solid, is at its *centre*; of any *parallelopiped* (or box-shaped figure) is at the *common crossing of its three diagonals*; of any *cylinder* is at the *middle point of its axis*; of an *oval or ellipse*, at the *crossing of its two axes*, or greatest and least diameters.

All these figures are evidently *symmetrical* about the centre of figure, that is, any straight line passing through the centre of the figure is divided into two equal parts there; and consequently, an equal number of molecules lying on each side of that centre in every direction round about, the whole must balance about that point.

198. Two masses, A and B, at the ends of a rod, will balance about a point midway between them if they are equal; and if B be greater than A, then the centre of gravity, or point about which they balance, will lie as much nearer B as B is greater than A.

199. A *triangular* or *three-cornered plate*, such as A B C (fig. 20), will balance about a line, A D, passing through one corner and the middle point of the opposite side, because just half of the plate lies symmetrically on each side of that line. Thus the centre of gravity lies somewhere in A D; it also lies in B E for a like reason. But it can only lie in both lines if it be at O, their common point of crossing. A little geometry shows that this point is situated so that O D is one-half of O A, or one-third of A D.

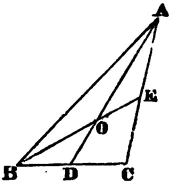

Fig. 20.

It is to be noted that the centre of gravity of *three equal masses* placed at the corners of the triangle would be the same point. Hence the placing of three equal weights or masses at the corners of a triangular plate already balanced, will not alter its balance.

It is to be noted, however, that the centre of gravity of *three rods forming a triangle*, differs from that of the triangular area which they contain, unless in the particular instance where the rods are all *equal.* Calculation shows that they balance about the centre of the circle, which can be inscribed within the triangle formed by joining the middle points of the rods.

200. A pyramid is a solid bounded by triangular faces, meeting in a point, such as is represented by A B C D, or by M N O P Q R S, in the figure, and such as would be enclosed by sheets ot paper cut like A B C D B′ and M N O P Q R S N′ in fig. 21, and folded along the lines drawn from A to the different corners.

As each of these triangular faces has its centre of gravity at a distance from A, two-thirds of the vertical height of A (art. 199), it is clear that the centre of gravity of the whole, when folded together so as to form the surface of a pyramid, will be vertically distant from A, two-thirds of the vertical height of A above the common base.

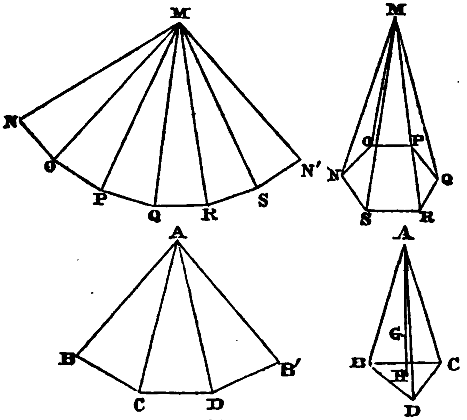

Fig. 21.

Since a cone is but a kind of pyramid with an infinite number of sides, just as a circle is a polygon with an infinite number of sides, the centre of gravity of a *conical surface* will, in like manner, lie in its axis at a distance from its summit or vertex two-thirds of its whole vertical height.

201. The centre of gravity of a *solid pyramid or cone* lies in its axis, or line drawn from the vertex to the centre of gravity of the base-area, and at a distance from the vertex three-fourths of the whole axial height.

" The centre of gravity seeks the lowest position."

202. Since the conjoint weight of a body acts as if concentrated at its centre of gravity, and the tendency of each particle is downwards, it is clearly the same thing to say that the centre of gravity of a body tends always to seek the lowest position possible under the circumstances. In a body hanging freely from a point, this position is, of course, vertically below the point of support; and if the body be moved from this position, its centre of gravity is raised, and will tend to fall back to it again.

The following cases, which appear at first to be exceptions to the law, are really interesting proofs of it.

A wooden cylinder or roller, *e d c* (fig. 22), placed on a slope, *a b*, will roll down, because its centre of gravity is thereby approaching the earth; but if there be a heavy mass of lead, *c*, introduced at one side, and if the roller be placed on the slope with the lead in the high position *d*, the lead, in falling down to the position *c*, will move the roller towards *b*, the apparent rolling up-hill being in truth a falling of the centre of gravity of the cylinder.

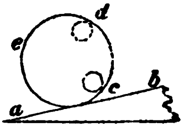

Fig. 22.

If a billiard-ball, *c* (fig. 23), be placed upon the smaller ends of two cues, *a b* and *c d*, laid on a table with their points, *c* and *a*, together, but with the larger ends, *b* and *d*, so far apart that there may be just room for the ball to touch the table between them, the ball will roll along between the cues towards the ends, *d* and *b*, appearing, to a superficial observer, to be rising when really its centre is descending in obedience to gravity. A double cone, such as *f*, would similarly roll from *c* to *e*, and with still more of the fallacious appearance of rolling upwards, because its sides would always be resting on the upper and rising surfaces of the cues.

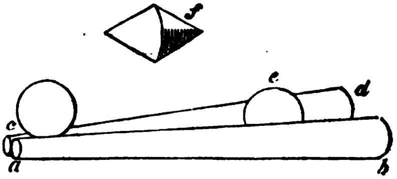

Fig. 23.

203. The beam or rod, *c d* (fig. 24), resting on the edge of the table, *a b*, would naturally fall if left to itself, because more than half of it is beyond the edge of the table; but, strange to say, an additional weight, *e*, attaching to its projecting part, as at *b*, by the cord, *b e*, instead of pulling it down faster, will fix or steady it on the table, provided the weight be pushed inwards a little by a rod, *d e*, resting against it and against a niche in the rod at *d*. It is evident that the rod, *c d*, in falling, must turn round the edge of the table at *b*; but in so doing, after the arrangement here-supposed, it must lift the weight, *e*, along the path, *e f*—which rise, as the weight is heavier than the rod (that is to say, as the common centre of gravity of the connected objects is near *e*), gravity prevents, and therefore the rod and weight will both remain supported by the table. An umbrella or walking cane, hanging on the edge of a table by a crooked handle, is an instance of the same kind. And the common toy of a little man standing on tiptoe upon the top of a pillar, and carrying in his hands two balls at the ends of a wire, is simply a combination of parts which places the centre of gravity of the whole below the support, in fact, a kind of pendulum.

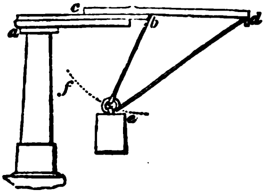

Fig. 24.

204. The following experiment will serve as a striking illustration of this principle. Plunge into a cork, at the end, *a* (fig. 25), the prongs of two short forks of equal weight, making an angle with the cork of about 45°. If the forks are properly adjusted, the extreme edge of the cork, *b*, will rest firmly and be supported in a horizontal position on the edge of the wine glass, *c*. The dotted line, *d e*, shows that there is an equal quantity of matter on each side of it, and the centre of gravity is right over *b*. The cork may be equally supported horizontally on the point of a pin. If the forks be brought a little more forward, the cork will rise, but will still be supported; if carried backward, it will remain supported, but sloping downwards. This, of course, depends on the change made in the position of the centre of gravity.

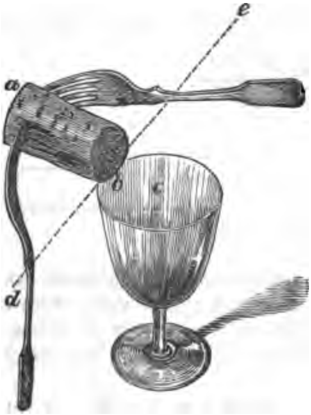

Fig. 25.

205. Attention must be paid to the form or position of a body when it is desired that it should not be readily pushed over or upset.

If, from its form or situation, a body cannot be overturned without its centre of gravity being lifted, its state of equilibrium or rest is said to be *stable*, that is, not easily disturbed, because, on being left to itself, it will by its gravity return to its old position. The rise of the centre of gravity in overturning, will depend on the breadth of the base compared with the height of the centre of gravity above the base. This is shown in the annexed drawings (fig. 26), which exhibit a series of combinations of *base* and *height*. The dot, *c*, marks the centre of gravity, and the curved line beginning from the dot marks the path of that centre, when the body is being overturned. This path is of course a portion of a circle which has the end of the base for a centre. The further inwards, therefore, that the centre of gravity is, horizontally, from the end of the base, the further of course is it from the top of the circle which it has to describe in moving, the steeper will be its commencing path, and the greater, consequently, will be the disturbance required to overturn the body.

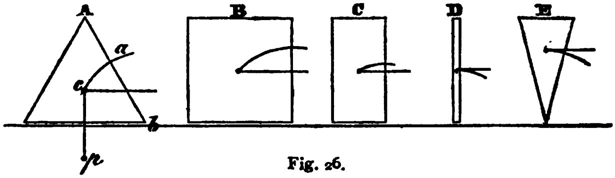

Fig. 26.

In the body A (fig. 26), which has a broad base with the centre of gravity low, this centre must rise almost perpendicularly before it can fall over, and the resistance to overturning is therefore nearly the whole weight of the body. Hence the firmness of a pyramid.

In B, C, and D, the path of the centre begins less and less steep as the base is narrower, and hence they are so much the less stable.

E is in a tottering position; for, the centre of gravity being directly over a base which is a mere point, the least inclination to either side places it on a descending slope, and the body must fall.

In F (fig. 27) the position is tottering on one side, and stable on the other. Hence the least inclination of a standing body virtually narrows, in one direction, its sustaining base.

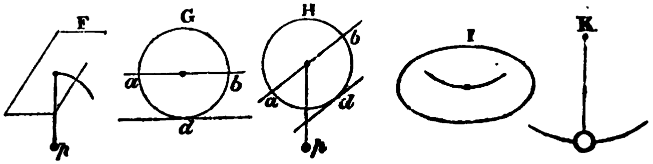

Fig. 27.

In G, a ball upon a level plane, the whole mass is supported on a single point as in E (fig. 26), yet the body has no tendency to move, because in every position the centre is at the same height above the sustaining plane, and, in moving, describes the straight level line, *a b*.

In H, the ball is on an inclined plane, and rolls down because it meets with no resistance in the line of its gravity.

In I, an oval body resting on a level plane, the centre of gravity has a motion somewhat like that of a pendulum when it is rolled to either side.

K is a true pendulum whose centre of gravity describes the curve shown.

"*Stable, unstable, and indifferent equilibrium.*"

206. The foregoing facts may be summed up in these words :—A body has its equilibrium *stable*, or does not readily fall, if the height of its centre of gravity be small compared with the extent of its supporting base; it has *unstable* equilibrium, or is in a tottering condition, if the centre of gravity is high compared with the size of its base; and its equilibrium or balance is indifferent, when any disturbance of the body does not alter the relation of the height of its centre of gravity to its base or support.

207. The importance of considering the position of the centre of gravity, relatively to the sustaining base, will appear in the following instances :—

A cart loaded with metal or stone may go safely along a road of which one side is higher than the other, when, if loaded with wool or hay, it would be overturned; because, as shown in figure 28, the low position of the centre of gravity, *c*, in the former case, throws the vertical line passing through it further from the limit of the sustaining base than in the latter, in which the centre of gravity is at *a*.

So stage coaches or vans are particularly dangerous when heavy luggage is placed on the top, and lofty vehicles are liable to be overturned by an unevenness of the road.

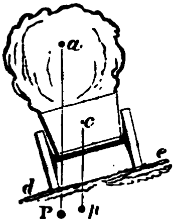

Fig. 28.

The centre of gravity being much higher when the crew of a small boat are on their feet than when they are seated, it requires very little to upset the boat in this case; and inattention to this, leads to many serious accidents.

Tripods, common chairs, pillar-and-claw tables, candlesticks, table-lamps, and many other articles of household furniture, have stability given to them by widening the base.

208. Any structure, such as a mass of masonry, will stand so long as the vertical line through its centre of gravity does not fall beyond its base; hence the famous tower of Pisa, with a height of 188 feet, though it overhangs sixteen feet, really has its centre of gravity vertically over its base.

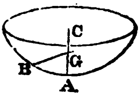

Fig. 29.

A solid hemisphere, or any regular portion of a solid globe, will oscillate like a pendulum till it come to rest in the position shown in the figure, because the height, G A (fig. 29), of its centre of gravity is then less than in any other position.

The boy's rocking-horse, the common cradle, and those huge rocking stones called Loggan stones, which are seen in Cornwall and other places, illustrate the same principle.

The common india-rubber toy of a little fat man sitting on a rounded pedestal is loaded with lead to throw the centre of gravity in the lowest position when the figure is upright, so that, on pushing the little man down we are really raising his centre of gravity.

209. The vibratory motion of a pendulum is dependent upon the circumstance of the centre of gravity having been moved from its lowest place, which it again constantly seeks. We may enumerate the following phenomena as being of the same class:—

The vibration of the common swing, seen at fairs.

The rocking of a balloon when it first ascends.

The spontaneous shutting of those gates or doors of which the upper hinge is made to overhang or project beyond the lower. Such a gate always returns of itself, from either side to the shut position, just as a pendulum returns to the lowest part of its arc; the gate in fact is a sloping pendulum.

Of the same nature also is the rocking or rolling of a ship in a rough sea. When the centre of gravity of a ship is too low, owing to much of its heavy load being placed near the keel, this pendulum-motion, in rough weather, becomes excessive and dangerous.

210. The attitudes of animals, particularly of man, illustrate the above remarks with respect to the centre of gravity.

The supporting base in man is the space included between the outer edges of his two feet, and it requires a great many trials to acquire the faculty of poising on this narrow base. On the other hand, quadrupeds, having a broad, supporting base, are able to stand, and even to walk and run, very soon after birth.

In drawing the human figure, the most stable position is given to it by causing a line passing from the junction of the two collar bones with the chest to fall in the centre of the space covered by the two feet. When this line falls near to the outer edges of the feet, it gives to the figure the appearance of instability, and if beyond the space covered by the feet, the attitude is that of falling. Artists are sometimes neglectful of this principle.

The difficulty of the art of walking must be considerably greater to the Chinese ladies, owing to their barbarous practice of preventing the growth of their feet by confining them in small shoes.

Artificial substitutes for legs are most inadequate supports when they consist merely of slender wooden stumps with rounded ends such as are exhibited by the victims of shipwreck and war. The addition of feet to such artificial limbs is not only more pleasing to the eye, but most important, on account of the extension it gives to the supporting base.

211. Surpassing in difficulty is the practice, which is general among the inhabitants of the sandy plains called the *Landes*, in the south-west of France, of walking on stilts. The *Landes* afford tolerable pasturage for sheep, but, during one portion of the year, are half covered with water, and during the remainder, are still very unfit walking-ground, by reason of the deep loose sand and thick furze. The natives meet the inconveniences of all seasons by doubling the length of their natural legs, through the addition to them of stilts, which they call *échasses*. Mounted on these wooden poles, which are put on and off as regularly as the other parts of dress, they appear to strangers a new and extraordinary race of long-legged beings, marching over the loose sand, or through the water, with steps of six or eight feet in length, and with the speed of a trotting horse; a possible journey being thirty or forty miles a day. While watching their flocks, they fix themselves in convenient stations, by means of a third staff which supports them behind, and then with their rough sheep-skin cloaks and caps, like thatched roofs over them, they appear like little watch-towers, or singular lofty tripods, scattered over the face of the country.

An example of poising the centre of gravity, even more difficult than that of walking on stilts, is that of walking and dancing on a single rope or wire; or even of keeping the centre of gravity above the base, while standing on the movable support of a galloping horse. A rope-dancer has to carry a long pole in his hand; it is loaded at each end, and when he inclines to one side he throws it a little towards the other side that the reaction may restore his balance.

Much art of the same sort is shown in the evolutions of the skater; in the supporting of a pole upright on the end of the finger; and in other feats of a like kind.

212. *Attitudes*, generally, depend on the necessity of keeping the centre of gravity of the body over the base under a variety of circumstances, as in—the straight or upright port of a man who carries a load on his head;—the leaning forward of one who carries it on his back;—the hanging backwards of one who bears it between his arms;—the leaning to one side of a person carrying a weight on the other side;—the habitual carriage of very fat people, with head and shoulders thrown back, giving a certain air of self-satisfaction.

When a man walks or runs, he inclines forward, that his centre of gravity may overhang the base; and he must then be constantly advancing his feet to prevent his falling. He makes his body incline just enough to produce the velocity which he desires.

So, in pulling horizontally at a load, he causes his body to overhang its base, that its weight may become a source of power.

When a man rises from a chair, he first bends his body forward or draws his feet backward, so as to place his base under his centre of gravity, and then he lifts his body up. If he rises before the body is sufficiently advanced, he falls back again.

A man standing with his heels close to a perpendicular wall cannot, without falling, pick up any object that lies before him on the floor; because the wall prevents him from throwing part of his body backward, to counterbalance the head and arms which have to project forward. For a similar reason, a person, standing with his side close to an upright wall, cannot lift the outside foot without assistance.

When a biped walks, the centre of gravity is brought alternately over the right and over the left foot, as is seen very strikingly in the waddle of a duck. The body advances in a waving line, and this is the reason why persons, walking arm-in-arm, shake each other, unless they make the movements of their feet to correspond, as soldiers do in marching.

213. *Sea-sickness* is a subject closely related to the present. Man requiring to keep his centre of gravity always over his supporting base, ascertains the requisite position in various ways, but chiefly by comparing the vertical situation of things about him with his own position. Vertigo and sickness are often the consequences of depriving him of his standards of comparison, or of disturbing them.

Hence, on shipboard, where the lines of the masts, windows, furniture, &c., are constantly changing directions, sickness, vertigo, and similar affections are common to persons unaccustomed to ships. Many persons are similarly affected in carriages, and in swings; or on looking from a lofty precipice, where known objects, being distant and viewed under a new aspect, are not so readily recognised; also in walking on a wall or roof; in looking directly up to a roof, or to the stars in the zenith, because then all standards disappear; on entering a round room, where there are no perpendicular lines of light and shade, as when the walls and roof are covered with a paper which has no regular arrangement of spots; on turning round, as in waltzing, or if placed on a wheel—because the eye is not then allowed to rest long enough on any standard, &c.

People when in the dark, and therefore blind people always, use standards connected with the sense of touch; and it is because, on board ship, the standards both of sight and of touch are lost, that the effect is so remarkable.

No doubt, sea-sickness depends partly also on the irregular pressure of the internal organs among themselves and against the containing parts, the result of their not being rigidly connected.

From the nature of sea-sickness, as discovered in these facts, it is seen why persons unaccustomed to the motion of a ship often find relief by keeping their eyes directed to the fixed shore, where visible; or by lying down on their backs, between supports, and shutting their eyes.

214. As no form or condition of matter escapes from the great laws of nature, we find the attitudes and general state of vegetable as well as of animal bodies, characterized by the necessity of having the centre of gravity supported over the base. Left to the guidance of nature, the springing pine rears its structure, alike on the level plane and on the rocky mountain side, straight up to the zenith as accurately as if directed by a plummet. On a smaller scale, the grasses and corn-stalks of our fields illustrate the same truth. And whenever, in tree or shrub, accident or peculiar nature causes a deviation from the vertical, additional strength and support are provided.

215. *Beauty of form or position* is often felt to belong to bodies, merely because they possess the shape and support required, that the centre of gravity may be stable.

In architecture, how displeasing to the eye of an observer is a wall or pillar that is not quite upright; or a column with too small a base; or a very tall narrow house; or a long slender chimney! On the other hand, how beautiful in a lofty edifice is the suitable succession of columns, from the massive Doric of the basement, supporting the whole superstructure, to the light Corinthian or kindred forms seen above! The Chinese pagoda is a fine example of the union of the requisites for stability, namely, perpendicularity and expanding base, with the other qualities of perfect symmetry, graceful proportion, and fanciful ornament. When seen in its own country, crowning a rising ground in a wooded island, or springing up from the centre of any rich landscape, it forms perhaps as beautiful an object as fancy has imagined.

216. *Beauty of attitude* and *grace of carriage* in the human figure may in great part be referred to the same principle.

The postures of opera dancers might pass as intentional illustrations of the number of ways in which the centre of gravity may be kept above a narrow base, by counteracting one disturbing motion or extension of a limb by some opposite and corresponding motion, The common statue of the god Mercury on tiptoe is a permanent familiar illustration of such a beautifully balanced attitude.

Grace of carriage includes a perfect freedom of motion, with a steady bearing of the centre of gravity over the base. It is usually possessed by those who live in a hilly country, taking much and varied exercise, or who make gymnastics a part of their discipline.

Great is the contrast between the gait of the active mountaineer and that of the mechanic or shopkeeper, whose confinement to the cell of his trade soon produces in his body a shape and air corresponding to it :—and in the softer sex what a difference there is between that strong and graceful fair one who recalls to us the fabled Diana of old, and that other sedentary being, who having scarcely trodden but on smooth pavements or carpets, carries her person, under any new circumstances, as if it were a load new and foreign to her.

217. The centre of gravity is the *centre of mass*, and therefore of any action or force which is uniformly distributed through the mass.

When a person lifts a uniform rod or bar by its middle, the gravitation of both ends being equal, he overcomes it equally, and raises them evenly together. When he lifts by a part nearer to one end there will be a turning motion of the rod round the support, proportioned to the excess of weight in the greater side.

If a weight of three pounds, *a* (fig. 30), be affixed to one end of a rod, and a weight of only one pound, *b*, to the other, the two will be equally raised if lifted by a point of the rod, *c*, three times nearer to the centre of the large weight than to the centre of the small one, that is, at the centre of gravity of the two masses, *a* and *b*. (For the sake of simplicity, the weight of the connecting rod itself is neglected.)

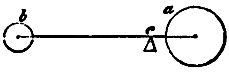

Fig. 30.

218. The *centre of gravity*, it is to be noted, is also the *centre of centrifugal force.*

For if the balls, *a* and *b*, of the last figure were made to spin round a common centre, as by turning upon a pivot at *c*, the centrifugal forces balance on each side of *c*, because the less velocity of *a* is compensated by its superior mass, and the smaller mass of *b* is aided by its greater velocity. It is on this account that the axis of a millstone, or of a great fly-wheel, or of the balance-wheel of a watch, must pass through the centre of gravity or mass, to prevent its being more worn on the one side than on the other.

Though we commonly say that the earth revolves round the sun, or that the moon revolves round the earth, it must be borne in mind that in all such cases, both bodies are revolving round their common centre of mass. In the case of the sun and the earth, the former is about a million times larger than the latter ; thus, their common centre of mass is a million times nearer to the centre of the sun than to the centre of the earth, and is therefore within the body or circumference of the sun.

219. The centre of gravity *in a body moving evenly* is also its *centre of percussion.* If the centre of gravity of a body be moving in a straight line, all its parts will be moving in parallel straight lines; and, the momentum being equally diffused through the whole, is as if condensed in this point. So that, if such centre come against an obstacle and is brought to rest, all the parts of the body will be brought to rest together; while if any other part than this centre be hit, the body loses only a part of its momentum, and then turns round the obstacle as a pivot or centre of motion, that side advancing on which the greater mass happened to be.

In a hammer, or in a pendulum, the momentum is not equally diffused through the whole, for the velocity of different parts is different, being greatest far from the centre of motion; thus, the centre of percussion in these cases is farther from the centre of motion than the centre of gravity or mass is, and if an obstacle meet either at its centre of gravity, the momentum would not be wholly given up.

220. The exact place of the centre of percussion in many cases is easily ascertained by calculation. In a uniform bar or rod swinging as a pendulum, for instance, it lies at the distance of one-third of its length from the lower end; and in a pendulum this is called the *centre of oscillation.*

If a man use a stick, or a bar of iron, to strike with, he must take care to make it strike the object by its centre of action or percussion, which will depend on the velocity given to the further end of the stick or bar. If, wielding the rod like a hammer, he were to strike an object by the centre of gravity of the rod, his own hand would receive a part of the shock, because the centre of percussion lying beyond the obstacle would tend to make the bar move round the object as a pivot. A very heavy mass thus carelessly used will seriously strain the wrist. In a common hammer, as the chief part of the mass is at the end, and the greatest velocity is given to it too, the centre of percussion is there, and no precautions are necessary.

In cricketing, the art of making a good hit depends on knowing by experience the proper spot of the bat with which to meet the ball.

With proper manipulation, a weaker man, or an inferior blow, may suffice to put the ball to a much greater distance than a stronger one. The "sting," with which all cricketers are acquainted, is caused by the ball meeting with great force the bat either within or beyond the centre of percussion; and it must be remembered that the more swiftly the batter wields the further end of his bat, the nearer to that end is the centre of percussion, and therefore is the proper spot to "take" the ball.

SECTION II.—THE SIMPLE MACHINES.

ANALYSIS OF THE SECTION.

By a combination called a MACHINE, *a force of small intensity may be made to act through a considerable space, and become transformed into one of increased intensity, acting through a proportionally diminished space, the substitution in the* form *of Energy being of great consequence to man in the accomplishment of his manifold purposes. The* SIMPLE MACHINES *are those which in this way transform* molar energy *or the energy of visible masses, and they are commonly enumerated as the* LEVER, *the* WHEEL AND AXLE, *the* INCLINED PLANE, *the* WEDGE, *the* SCREW, *the* PULLEY. *From an erroneous idea of the principles involved, these were formerly designated the* MECHANICAL POWERS; *but there is no reason but old usage why the title should be confined to them, any arrangement of parts which connects or exchanges different intensities of force being equally worthy of the name.*

The action of all machines is either (i.) *to effect such transformation of* intensities *of energy* directly, *or* (ii.) *to do it by the* cumulative principle, *as in slings, brakes, fly-wheels, &c., or* (iii.) *to effect merely a* directive *change of motion, as of horizontal into vertical, of rectilinear into rotatory, or of rotatory into rectilinear motion, the last being an important conversion, though troublesome to effect by rigid mechanism, as is proved by the many futile attempts to obtain a* PERFECT PARALLEL *motion.*

In all machines due account must be taken (i.) *of the resistance among the moving parts owing to* FRICTION, *which wastes Energy to no purpose, and* (ii.) *to the* STRENGTH OF THE MATERIALS *of which the machine is made, as well as to the forms and positions of the structure which have to be adjusted to the strains that the different parts have to bear.*

The Simple Machines.

221. The Energies or forces of nature at our command for the accomplishment of the thousand kinds of work to be done are few in number, as has been seen; and, in many situations, we are confined to one. This one may be unsuited to our purpose in the form in which nature gives it. For example, a waterfall is unfit to grind corn; and horse-power is unadapted to spin wool or draw water from a depth. By a combination of solid parts, or a *machine*, these energies may be made to answer the purpose required. A small stream of water falling a great height may do the work of a large volume falling a less height; or a horse may be used for drawing water, and so perform each day the work of ten men.

But in no case is there anything more than a remoulding of the Energy supplied by nature, a mere translation of it from one form into another.

222. Machines which recast the simpler form of Energy, the motions of visible or molar masses—translating a long-continued motion of a small mass into a less motion of a larger mass, or the reverse—are usually called the *Simple Machines*, and sometimes the *Mechanical Powers*. The latter term, however, is based on a false and very misleading notion, namely, that these machines *increase the quantity of force* applied to them or are in themselves somehow a source of *power*.

223. It is seen, for instance, that one pound at the end of a beam just balances two pounds at *b* (fig. 31), half the distance on the other side of the axis, or four pounds, at *c*, a quarter of the distance; and many persons believe that the beam or lever itself begets a force equal to the difference of the weights so balanced. The explanation of the apparent paradox follows at once from the notions of force and Work, already explained in Section II.

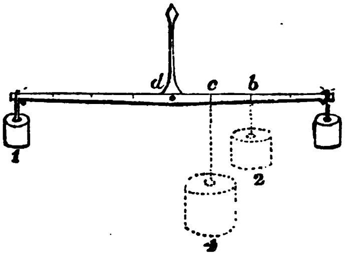

Fig. 31.

The same amount of force which gives a certain velocity to four pounds is just that required to give four times the velocity to one pound; and, owing to the connection of the two weights through the beam, no motion downwards by gravity can occur in the four pounds without causing a motion upwards just four times as great in the one pound. These two tendencies being equal and directly opposed to each other, must exactly balance, and no motion whatever of the beam will be produced.

224. To illustrate this further, suppose a weighing-beam, *x y* (fig. 32), with one pound hanging at the end, *x*. Now if a spring, issuing from the fixed box at E with a force of one pound, be made to push at the other end of the beam, *y*, it will just balance the weight; and if it be in the slightest degree stronger than the weight, it will push the end of the beam, *y*, down to B, say two inches, and will raise the weight to F. If, instead of this single spring, two similar springs be applied at half-way from the centre, so as to press at A, where there is just half the extent of motion, or room to act, as at B, exactly the same effect will follow. Now, because one spring at the end of the beam is seen here doing the same Work as two similar springs, or a single spring of double strength at the middle, it might at first appear that there was a saving of power by using the single spring and longer lever; but let it be observed, that the two middle springs have each issued from their box only one inch, while the single spring at the end has issued two inches: in both cases, therefore, exactly two inches of one-pound spring have been used.

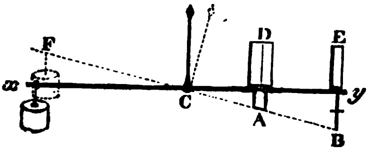

Fig. 32.

Each atom of matter may be considered as held to the earth by its thread of attraction, and if one atom rise or fall ten inches, just as much of the supposed thread of attraction will be drawn out or returned as if ten atoms rise or fall one inch. And so, where a weight of one pound is made to do any Work, in place of a weight of two pounds, there is no more saving than in giving away two yards of single rope instead of one yard of double rope; and in like manner for all other differences of intensity.

225. If a man were to exert a force of one hundred pounds at A (fig. 32), in order to lift the weight, a boy at B, with a force of fifty pounds, might do just the same work; but the man would only have worked or pressed down through one foot, while the boy would have worked through two; and therefore, although the boy with the assistance of the lever, seemed to become as strong as the man, the case would merely be, again, that of the one-pound spring unbending two inches, to produce an effect equal to that of the two-pound spring unbending one inch. The boy would be using two feet of his smaller force, where the man used one foot of his greater force; and if the work had to be long continued, the boy would have completely exhausted himself when the man remained yet fresh; and there would be no economy in employing the boy's services instead of the man's.

226. A case of the *lever*, exhibited in fig. 33, serves well to explain the general principle of the so-called *mechanical powers.* Suppose A B a bar, with the arm, *c* B, four times as long as the arm, *c* A, but the two arms equipoised so as not to disturb the action of weights subsequently attached to them. Then one pound at the end, B, would just balance four pounds at the end, A. Let us suppose also the arc, B *b*, to have been fixed to the long arm of the bar or lever with the four shelves here shown, on which balls of one pound each might rest. If one of the four balls from the plane, *d*, were to roll upon the first shelf, it would just balance A, and, with one grain more, would descend to the level of the plane *e*, one inch below, and then roll off; while a second ball of one pound would occupy the second shelf, and would descend in the same way, to be followed by a third, and afterwards by a fourth. Now, when the whole four had fallen from *d* to *e*, they would just have lifted the four-pound mass, at the other end of the lever, one inch. So that, although one pound were seen here lifting a weight of four pounds, it would only have lifted that one-fourth part as far as it fell itself; and the whole resolves itself into an *exchange* of four pounds falling one inch at the long end of the lever for four pounds rising through the same distance of one inch at the short end.

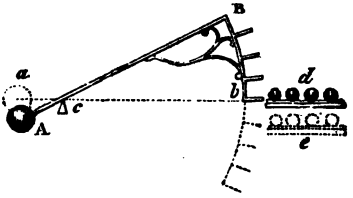

Fig. 33.

No mechanical power or machine generates force more than is done in this case.

227. What an infinity of vain schemes—and some of them displaying great ingenuity—for *perpetual motion*, and new mechanical engines of power, would never have been attempted had the great truth been generally understood, that no form or combination of machinery ever did or ever can *increase*, in the slightest degree, the amount of power applied! Ignorance of this is the hinge on which most of the dreams of mechanical projectors have turned. The delusion of a perpetual motion which even men of talent have often fallen under, owing to their imperfect knowledge of this branch of natural philosophy is a remarkable phenomenon in human nature.

228. The mechanical powers, usually enumerated as the *lever*, the *pulley*, the *inclined plane*, the *wheel and axle*, the *wedge*, and the *screw*, will now be considered in detail.

"*Lever.*"

229. A beam or rod of any kind, resting at one part on a prop or axle as a centre of motion, is a lever; and it has been so called, probably because such a contrivance was first employed for *lifting* weights (*levo*, to lift, in Latin).

Fig. 34 represents a lever employed to move a heavy block: *a* is the end to which the *power* or *force* is applied, *f* is the *prop* or *fulcrum*, and the mass, *b*, is the *weight* or *resistance*. According to the rule already given and explained at page 122, the power may be as much less intense than the resistance, as it is farther from the fulcrum. A man at *a*, therefore, twice as far from the prop as the centre of gravity of the stone *b* is, will be able to lift a stone twice as heavy as himself; but he will lift it only one inch for every two inches that he descends: and two men would be required, acting at half the distance, to do the same work.

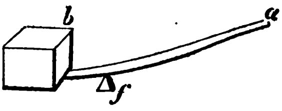

Fig. 34.

There is no limit to the difference, as to intensity, of forces which may be made to balance each other by the lever, except the length and strength of the material of which levers may be formed. Archimedes said, "Give me a lever long enough, and a prop strong enough, and with my own weight I will lift the world." But it is a matter of simple arithmetic to show that he would have required to move with the velocity of a cannon-ball for millions of years, to alter the position of the earth by a small part of an inch.

230. To calculate the effect of a lever in practice, we must always take into account the weight of the lever itself, and the fact of its bending more or less; but, theoretically, it is usual to consider, first, what would be the result, if the lever were a rod without weight and without flexibility.

The rule, that the opposing forces, to balance each other, must be greater or less, exactly as they act nearer to or farther from the centre, holds in all cases, whether the forces be on different sides of the prop or both on the same side, and whether the force nearest to the prop have the office of power or of resistance; it holds also, whether the lever be straight or crooked, provided we reckon the distances from the fulcrum along the perpendiculars from that point on the lines of action of the balancing forces.

231. The lever is commonly described as of the *first kind*, if the fulcrum be placed between the power and the weight or resistance (P. F. W.); of the *second kind*, if the fulcrum be beyond the weight, so that the power and weight are on one side, the weight nearest the fulcrum (P. W. F.); and of the *third kind* if the power be nearer the fulcrum than the weight (W. P. F.).

232. The following are examples of the first kind of levers, i.e., with the prop between the forces.

The *handspike*, represented in page 123, is a lever moving a block of stone. The same form when made of iron, with the extremity formed into claws, is called a *crow-bar*. These are used generally for lifting and moving heavy masses through small spaces, as the materials of the mason, the shipbuilder, the warehouseman, &c. A short crow-bar is the instrument used by housebreakers for wrenching open locks or bolts, tearing off hinges, &c.

The common *claw-hammer*, for drawing nails, is another example. A boy who cannot exert a direct force of fifty pounds, may yet, by means of this kind of hammer, extract a nail to which half a ton might be quietly suspended without drawing it, because his hand moves through perhaps ten inches, to make the nail move a small part of an inch. The claw-hammer also proves that it is of no consequence whether the lever be straight or crooked, provided it produces the required difference of velocity between power and resistance. The part of the hammer resting on the plank is the fulcrum.

In the *pincers* or *forceps* we have a double lever, of which the hinge is the common prop or fulcrum. In drawing a nail with steel forceps or nippers, we have a good example of the advantages of using a tool: 1. The nail is seized by the steel teeth instead of by the soft fingers: 2. Instead of the griping force of the extreme fingers only, there is the force of the whole hand conveyed through the handles of the nippers: 3. The force is rendered many times more effective by the lever-length of the handles: and 4. By making the nippers, in drawing the nail, rest on one shoulder as a fulcrum, it acquires all the advantages of the lever or claw-hammer for the same purpose.

Common scissors are double levers, as are also those stronger *shears* with which, under the power of a steam-engine, bars and plates of iron are now cut as easily as paper is cut by the force of the hand.

The common *fire-poker* is a simple lever. It rests on the bar of the grate as its prop, and displaces or breaks the caked coal behind as the resistance.

The *mast of a ship*, with sails set upon it, acts sometimes as a long lever, having the wind filling the sails as the power, turning upon the centre of buoyancy of the vessel as the fulcrum, and lifting the weight at the centre of gravity as the resistance. For this reason lofty sails make a ship heel or lean over greatly, and if used in open boats, are dangerous. In some of the islands in the Eastern and Pacific Oceans, for the sake of sailing swiftly, boats are used so extremely narrow and sharp, that to counteract the overturning tendency of their large sails, they have an *outrigger* or projecting plank to windward, on the extremity of which one or more of the crew may sit as a balance.

No instance of the lever that has the prop between the forces is more interesting than the *weighing-beam* or balance: whether with equal arms, forming the common *scale-beam*, or with unequal arms, forming the *steelyard*.

The Common Balance or Weighing Beam.

233. We have seen (223) why quantities of matter, attached at equal distances from the prop, must be equal to each other in order to balance. A lever, therefore, which enables us to place masses thus exactly in opposition to each other, and which turns easily on its axis, becomes a weighing-beam. Of this the annexed figure shows a common form. The axis or pivot at *c* is sharpened below, wedge-like, that the beam may turn easily, and that its centre of motion may be nicely determined;—in a delicate balance for philosophical purposes, the axis is almost sharp as a knife edge, and rests on some hard smooth surface of support, so as to turn with even the thousandth part of a grain. The scales also of a weighing beam are suspended on sharp edges, to facilitate motion, and to determine nicely the points of suspension. If the two arms of a beam be not of exactly equal length, a smaller weight at the end of the longer will balance a greater weight at the end of the shorter. An excess of a tenth or other proportion in the length of a beam-arm, to which merchandize is attached, would cheat the buyer of exactly that proportion of his purchase. This case may be detected instantly, by changing the places of the two things balanced; for so, the lighter would be at

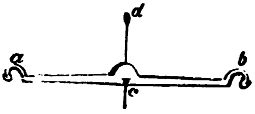

Fig. 75.

the short arm, and would then appear doubly light. A beam intended for delicate purposes, and required, therefore, to turn easily, must have its centre of gravity very near the axis on which the beam turns; for if otherwise, the beam will be in the predicament of a ship with the ballast either too high or too low: in the former case, when once inclined, it would fall over, and could not recover itself; in the latter, it would tend too strongly to remain horizontal, and therefore would be less free to move. The proper situation of the centre of gravity is a little below the axis or line of support, so that the beam may return with sufficient readiness from any state of inclination to its horizontal position of rest.

234. It is possible but troublesome to weigh very accurately even with a weighing-beam which is not itself accurately made, provided it has very free motion. First balance very nicely in one scale the substance to be weighed by sand or other matter put into the other; then remove the substance, and put weights into the same scale, until a perfect balance is again produced. Such weights will be the exact equivalent or weight of the substance, however unequal the arms of the balance may be. A projecting rod or plank or branch of a tree, may thus be made to answer the purpose of a weighing-beam, by first attaching the substance to be weighed to its extremity, and observing minutely how far it bends, and then trying what weights will bend it as much.

235. The *steelyard* is a lever of the *first kind* with unequal arms, and any weight, as *b*, on the long arm (fig. 36), will balance a weight, *a*, on the short arm, as much more as the former is farther from the fulcrum than the latter. Thus, if the hook at the short end be one inch from the centre of support, *c*, a pound weight, *b*, on the long arm, at four inches, will balance four pounds, *a*, at the short arm. This supposes, however, that the steelyard when bare hangs horizontally, from having a greater mass of matter on the short arm to counterbalance the long slender arm from which the shifting weight hangs. When this is not the case, a corresponding allowance has to be made.

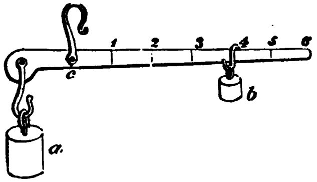

Fig. 36.

The Chinese, who are so remarkable for the simplicity to which they have reduced all their common implements, weigh any small objects by a delicate pocket steelyard. It is a rod of wood or ivory, about six inches long, with a silk cord passing through it at a particular part, to serve as a fulcrum, and with a sliding weight on the long arm, and a small scale attached to the short one.

236. The following are examples of levers of the *second kind* with both forces on the same side of the prop or fulcrum, and where the more distant force acts as the power.

A common wheelbarrow is a lever of this sort, in using which a man bears as much less than the whole weight of the load, as the centre of gravity of the load is nearer to the axle of the wheel than to his hands.

When two porters carry, on a pole, *a b* (fig. 37), a load placed midway between them, as at *c*, each bears a half, for the pole becomes a lever, of which each porter is a fulcrum, as regards the other ; but if the load be at *d*, the man at *a* bears three-quarters of its weight, and the man at *b* only one-quarter, the latter being three times as far from the weight as the former.

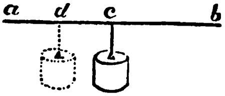

Fig. 37.

Two horses drawing a plough act from the ends of a cross bar, of which the middle usually is hooked to the plough. The horses must thus pull equally, to keep the bar directly across. When, on heavy land, three horses are yoked, and two of them are made to draw from one end of the bar, it must be attached to the plough by a hook, not at its middle, but half as far from one end of it as from the other.

The oar of a boat is a lever of this kind, where singularly the purpose of fulcrum is momentarily served by the unstable water.

The common nut-crackers may cited be as another instance, by the lever-power of which a person can break a shell many times stronger than he could break with the bare fingers.

The consideration of this kind of lever explains why a finger caught near the hinge of a shutting door is so severely crushed. The momentum of the door acts by a comparatively long lever, upon a feeble resistance placed very near the fulcrum.

The circumstance of the branch of a tree giving way, when in autumn overloaded with fruit, or in winter with snow, also exhibits the action of this kind of lever. The resistance is the cohesion of the upper side of the branch, and the fulcrum is the part below which is last broken.

237. The following are examples of the lever of the ***third kind***, where the two forces are on the same side of the pivot, but where that nearest to the pivot acts as the power. In this kind, the power is greater than the resistance.

The hand of a man, who pushes open a gate while standing near the hinges, moves through much less space than the end of the gate, and hence must act with great force.

When a man uses the common fire-tongs, the ends move much farther than his fingers, and therefore with less strength. No one fears a pinch thus given with the ends of the fire-tongs.

Beautiful instances of this modification of lever are exhibited in the limbs of animals. In these the distant extremities, as the hand or foot, require to have great range and freedom of motion, without clumsiness of the limb; and the object has been attained most perfectly by the tendons or ropes which move the limbs being attached near to the joints, which constitute the pivots or fulcra of the bone-levers.

In the human arm, the deltoid muscle, which forms the cushion of the shoulder, by contracting its fibres less than an inch, can raise the hand a yard or more; and of course, if it overcome a force of many pounds placed there, it must itself be acting with a force very intense. What extraordinary strength of muscle, then, is displayed by a man who lifts another man at the end of an extended arm!

How powerful, again, must be the wing-muscles of birds, which, by this kind of action, sustain themselves in the sky for many hours together! The great albatross, with wings extended fourteen feet, is seen in the stormy solitudes of the Southern Ocean, accompanying ships for whole days, without ever resting on the water.

A contraction of about one inch of the glutei muscles of the hip gives to the human step a length of four feet.

While the erroneous opinion prevailed, that machines *increase* power, instead of, as they do, merely *accommodating* forces to purposes, this last kind of lever, where a great force acting through a short distance is made to give great extent of motion and other benefits, was viewed by many as an unprofitable contrivance, and was called the *losing lever.*

238. It is almost unnecessary to say, that the same rule of comparative velocities ascertains the relations required between power and resistance, where a *combination* of levers is used, as where there is only one. If a lever which makes *one* balance *four*, be applied to work a second lever which does the same, *one* pound at the long arm of the first will balance *sixteen* pounds at the short arm of the second, and would balance *sixty-four* at the short arm of a third, and so on.

239. The general rule for the lever, that a force may be less intense the farther it is from the pivot, supposes always that the force acts at right angles, or directly across the lever; for if there be any obliquity, there is a corresponding diminution of effect, as explained under the head of *resolution of forces*, at page 57. For instance, one pound at *b* on the end of the long arm of the bent lever, *b d a*, has influence only as if it were acting directly at the end of a shorter horizontal arm, *d f*, because its weight does not act directly across *b d*; and the two-pound weight at *a* acts only as if it were on a horizontal arm, *d e*; now *e* being only half as far from the centre as *f*, two pounds at *a*, in the position of the lever here shown, would just balance the one pound at *b*. In every case, the exact influence of weights is known by referring them to places directly above or below them, on a supposed horizontal lever, *e f*.

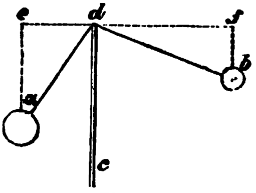

Fig. 38.

The *bent-lever balance*, in common use for letter-weighing, is made on the principle here explained. It has on one side a heavy weight as at *a*, and on the other side a scale attached at *b*; and the weight of anything put into the scale is indicated by the position then assumed by the lever, marked by the point at which it cuts an arc of divisions placed behind it. In any common weigh-beam, the point of suspension of the scales being a little below the axis of motion of the beam, there is to a certain degree the property of the bent-lever balance, enough to require notice in very nice experiments.

"*The Wheel and Axle.*"

240. The next of the simple machines is the wheel and axle (fig. 39); *d* marks a wheel, and *e* an axle affixed to it. In turning together, the wheel would take up, or throw off, as much more rope than the axle, as its circumference or diameter were greater than that of the axle. If the proportions were as four to one, a pound at *b*, hanging from the circumference of the wheel, would balance four pounds at *a*, hanging from the opposite side of the axle. The proportions are equally in-

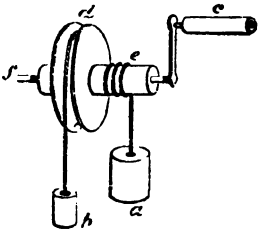

Fig. 39.

dicated, and are usually expressed, by comparison of the diameters of the wheel and the axle. Instead of the wheel, *d*, here shown, the handle or winch, *c*, may be substituted as explained in Art. 241.

Fig. 40 is an end view of the same object. It explains why the wheel with its axle has been called a perpetual lever; for the two weights hanging in opposition, on the wheel at *a*, and on the axle at *b*, are always as if they were connected by a horizontal lever, *a c b*, whose arms are the half-diameters of the wheel and the axle, and fulcrum their centre, *c*; and while a simple lever could only lift through a small space, it is evident that this construction will lift as long as there is rope to be wound up.

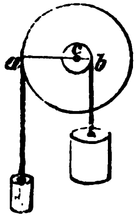

Fig. 40.

A common crane for raising weights, consists of an axle to wind up or receive the rope which lifts the weight, and of a winch or a large wheel, at the circumference of which the power is applied. The power may be animal effort exerted on the rim or outside of the wheel, or the Energy supplied by a steam engine.

241. The *capstan*, used on board of ships, is merely a large upright axle or spindle, *b*, which by turning pulls the cable or rope, *a b c* (fig. 41). It is moved by the men pushing at the capstan-bars, *d*, *e*, *f*, which for the time are placed in holes in the broader part, *i*, or drum of the capstan, usually appearing above the deck, at the top of the spindle. These bars may be considered as the spokes of a large wheel, and the effect produced by a man working at one of them, is in proportion to his distance from the centre. The capstan is chiefly used on board ships for lifting the anchor, and for doing any other very heavy work. It is applied also to various purposes on shore.

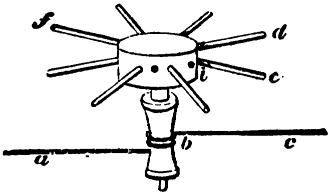

Fig. 41.

The common *winch* with which a grindstone is turned, or a crane worked, or a watch wound up, is really in principle a wheel: for the hand of the worker describes a circle, and there is no difference in the result whether an entire wheel be turning with the hand or only a single bent spoke of a wheel.

242. The *fusee* in a watch is a beautiful illustration of the principle of the wheel and axle. The spring of a watch, immediately after winding up, being more strained, is acting more powerfully to drive on the wheels than afterwards when slacker, and it would destroy the wished-for uniformity in the motion of the time-piece if there were no means of equalising its action. The fusee (fig. 42) is this means. It is a barrel or spindle, tapering from its large end, *b*, to its small end, *a*, with a spiral groove cut in the surface to receive the chain, by pulling at which, the spring in the box, *c*, moves the watch. Now when the watch has been wound up, by a key applied on the axle of the fusee near *a*, the fusee is covered with the chain up to the small end, and the newly bent and strong spring begins to pull by this small end or short lever; and afterwards, exactly as the spring becomes relaxed and weaker, it is pulling at a larger and larger part of the fusee-barrel, and so keeps up an equal or uniform effect on the general movement.

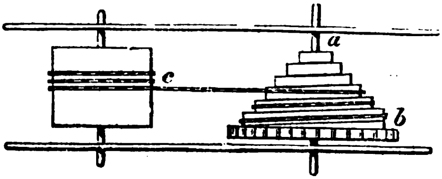

Fig. 42.

In place of a common cylindrical axle, a large fusee is often used with a winch, for drawing water by bucket and rope from very deep wells. When the bucket is near the bottom of the well, and the labourer has to overcome the weight of the long rope, in addition to that of the bucket and water, he does so more easily by beginning to wind the rope on a small axle, that is to say, on the small end of the fusee; and in proportion as the length of rope diminishes, he lifts by a larger axle.

The same thing happens, in principle, when the rope, by coiling on itself, increases gradually the diameter of the axle

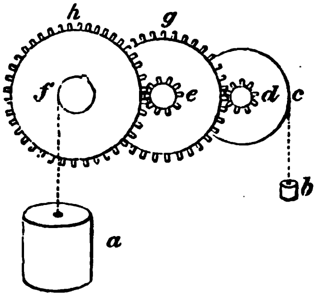

Fig. 43.

243. By means of a wheel, which is very large in proportion to its axle, forces of very unequal intensities may be balanced, but the machine becomes of inconvenient proportions. It is found preferable, therefore, when such an end is desired, to use a combination of wheels of moderate size. In the adjoining cut (fig. 43) three wheels are thus connected. The teeth on the axle, *d*, of the first wheel, *c*, acting on six times the number of teeth in the circumference of the second wheel, *g*, turn it only once for every six times that *c* turns; and in the same manner the second wheel, by turning six times, turns the third wheel, *h*, once; the first wheel, therefore, turns thirty-six times for one turn of the last; and as the diameter of the wheel, *c*, to which the power is applied, is three times as great as that of the axle, *f*, which bears the resistance: 3 times 36, or 108, is the proportion of velocity, and therefore of intensity, between weights or forces that will balance here. An axle with teeth upon it, as *d* or *e*, is called a *pinion*.

On the principle of combined wheels, *cranes* are made, with which one man, by working a long time, can lift many tons. It is even possible to make an engine, by means of which a tiny windmill, of a few inches in diameter, should eventually tear up a strong oak by the roots.

The most familiar instances of wheel-work are in our clocks and watches. A few turns of the axle on which the watch-key is fixed, are rendered equivalent, by the train of wheels, to more than ninety thousand beats of the balance-wheel; and thus the exertion during a few seconds, of the hand which winds up, gives steady motion for more than twenty-four hours. By increasing the number of wheels, a time-piece might be made to go for years.

Wheels may be connected by *bands* as well as by teeth. This is seen in the common spinning-wheel, turning lathes, grind-stones, &c. A spinning-wheel, as *a c* (fig. 44), of twenty inches in diameter, turns by its band a bobbin or spindle of half an inch diameter, *b*, forty times for every turn of itself (or nearly so, for there is always more or less slipping of the band to be allowed for).

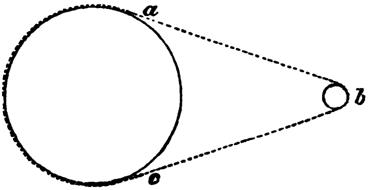

Fig. 44.

244. *The inclined plane* is the third means of balancing, by solid media, forces of different intensities.

When a force is applied to move a weight from *c* to *d* (fig. 45), by acting along the whole length of the plane *c d*, it has to *raise* it through only the perpendicular height *e d*; and if the plane be twice as long as it is high, one pound at *b*, acting over the pulley *d*, would balance two pounds at *a*, or anywhere on the plane: and so of all other quantities and proportions, as already explained under the head of "Resolution of forces."

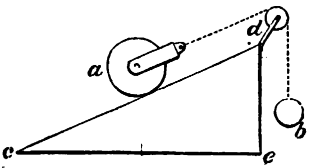

Fig. 45

A horse drawing on a road where there is a rise of one foot in twenty, is thus really lifting one-twentieth of the load, as well as overcoming the friction and other resistance of the carriage. Hence the importance of making roads as level as possible; and our forefathers often erred in carrying their roads directly over hills, for the sake of straightness considered vertically, where by going round the bases of the hills they would scarcely have had greater distance, and would have avoided all rising and falling. A road up a very steep hill is usually made to wind or zig-zag all the way; the ease to the horses being greater exactly as the road is made longer. The fatigue of ascending a high column is lessened by making the ascent an inclined plane winding round and round, and lessened just in proportion as the route is made longer than the height of the column.

245. Railways offer a beautiful illustration. When the line is perfectly level, the steam-engine which draws the train has just to overcome the friction of the carriages and the resistance of the air; but if there is a rise of 1 foot in 40, or 1 in 60, or 1 in 120, the engine has then the additional work to do of lifting vertically up $\frac{1}{40}$th, or $\frac{1}{60}$th, or $\frac{1}{120}$th of the weight of the whole train.

A hogshead of merchandize, which ten men could not lift directly, may be rolled into or out of a waggon by one or two men, who have the assistance of two connected beams forming an inclined plane. There are some canals where, in particular situations, it is found convenient to have the loaded boats drawn up by machinery on inclined planes, instead of being raised by water in locks, as elsewhere.

It is supposed that the ancient Egyptians must have used the inclined plane to enable them to put in position those immense blocks of stone, which still remain marvels of their gigantic architecture.

Our common stairs are inclined planes; but, being so very steep, they require to be notched into steps, that they may afford a firm footing.

enables the instrument maker and mechanic to mark divisions on his work with a minuteness and accuracy very marvellous. If we suppose such a screw to be pulling forward a plate of metal, or pulling round the rim of a circle, over which a sharp-pointed steel marker can be let down perpendicularly from always the same place, clear lines may be drawn so fine and so close as to be readable only with the aid of a microscope.

The instruments called micrometers, by which the sizes of the heavenly bodies and of microscopic objects are ascertained, are worked by fine screws.

An *endless screw* is one which acts on a toothed wheel, producing a rotation of the wheel always in the same direction, one tooth passing for every turn of the screw.

A common corkscrew may be regarded as the worm of a screw detached from the central spindle ; it is used, not to produce motion or to balance opposing forces, but merely to pierce and fix itself in the cork.

250. *The pulley*

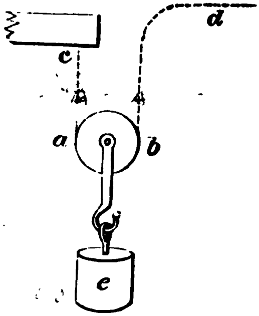

Fig. 48.

is another *simple machine*, by which masses moving with different velocities may be connected, and thus forces of different intensities balanced. A simple pulley consists of a wheel, as *a b* (fig. 48), with a grooved circumference, by which a rope, *c a b*, may be passed round ; the weight or resistance, *e*, being attached to the axle of the wheel.

In such a construction, it is evident that the weight (say, one hundred pounds) is equally supported by each ply or length of the rope, and that a man holding up one end, while the other is attached to a fixed support, only bears half the weight, or fifty pounds. But to raise the weight one foot, he must draw up two feet of rope ; therefore the pulley enables him, by lifting fifty pounds two feet, to raise a hundred pounds one foot. There is here no *saving* in the expenditure of Energy, but an important *modification*, which adapts the limited intensity of power belonging to the animal frame to the overcoming of vastly increased intensitv of resistance.

251. Pulleys may be combined in several ways. Where there is but one rope used, as shown in fig. 49, the relation of velocities, and therefore of power and resistance, is known by the number of plies or lengths of the rope supporting the weight, each bearing its due proportion. Here there are four supporting folds, so that a weight of twenty-five pounds moving four feet would balance a weight of one hundred pounds moving one foot. The upper fixed pulley evidently serves no other purpose than that of enabling a *downward* pull to give the necessary support to the weight.

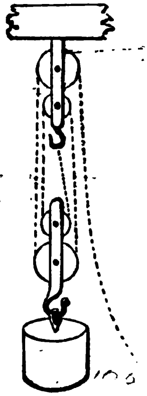

Fig. 49.

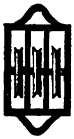

Fig. 50.

In practice the pullies are usually arranged, as in fig. 50, in one block, and having a single axle, so that the sheaves are side by side, in place of being one below another. But the mode of estimating the velocity-conversion is exactly the same. In modern mechanical language, the pulley is denominated the *machine of reduplication.*

252. In *fixed pulleys,* like those shown at *a* and *c* (fig. 51), there can be no difference of velocity at the two extremities of the rope, for the weight just moves as fast as the power; and such pulleys are of use only in changing the direction of forces. Yet this is often of very great importance. A sailor, without moving from the deck of his ship, may, by means of such a pulley, hoist the sail or the signal-flag to the top of the loftiest mast. And in building, where heavy loads of material are to be elevated every few minutes, a horse, trotting away with the end of the rope from *d,* in a level court-yard, raises the weight or charged basket, *b,* as effectually as if he had the power of climbing, at the same rate, the perpendicular wall.

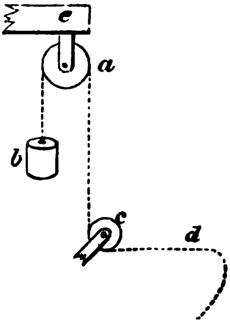

Fig. 51.

There is a case, however, in which a fixed pulley may seem a balancer of different intensities of force; viz., where one end of a rope is attached to a man's body, and the other is carried over a pulley above, and brought down again to his hands, or to a weight taken to assist him. By pulling then, with a force equal to half his weight or less, he supports himself, and may easily raise himself to the pulley. A man, by a pulley thus arranged, may let himself down into a deep well, or from the brow of a cliff, with assurance of being able easily to return, although no one be near to help him ; and cases have often occurred where, by such means, a fellow-creature's life might have been saved. How easily, for instance, might persons either reach or escape from the elevated windows of a house on fire by means of such a pulley, when ladders could not be obtained ! This kind of pulley furnishes a convenient means of taking a plunge bath from the stern windows of a ship.

The chief use of the pulley is on shipboard. It is there called a *block*, although strictly speaking, the block is only the wooden frame which surrounds the wheel or wheels of the pulley. It aids so powerfully in overcoming the heavy strains of placing anchors, hoisting the masts and sails, &c., that by means of it a smaller number of sailors are rendered equal to the duties of the ship. Pulleys are also used on shore, instead of cranes or capstans, for lifting weights and overcoming other resistances.

Surgeons in former days, when they trusted to mere force, used pulleys, with unnecessary violence, in the reduction of luxations.

The cranks by which bell wires are carried round corners into the different rooms of a house, are nearly equivalent to fixed pullies. Railway signals are, by means of such pullies, now conveyed long distances, so that a man at a station can, without moving a step, lower or raise the warning hand to the approaching engine-driver.

253. Excepting old usage, there is no reason why the term *mechanical power* should have been confined to the six contrivances above described.

Any connection of solid or rigid parts moving with different velocities will equally transform Energy from one degree of intensity to another, and therefore equally merits the title of mechanical power. But the needs for the raising of great weights and the overcoming of great resistances were for a long time satisfied by the *simple machines* we have enumerated.

In the light of the modern doctrine of Energy, we know that a machine cannot create the smallest amount of force or power. If a man, with a couple of five-sheave pulley blocks and a rope, can raise a weight which it would take ten men to move directly, still he has to continue his exertion just ten times as long as the ten men would have to do; and a work which would last the ten men a whole day would last the one man ten days; there would be just ten days' wages to pay in both cases, and therefore no saving of human effort.

254. Machines, then, are but modifiers of motive energy; and this modification may take one or other of the following three forms :—

(i.) The connected parts may be so arranged as to move with different velocities; thus, a mass of one pound moving at one velocity will correspond to a different mass (say two or three pounds) moved at another velocity.

The simple machines fall under this head; the lever, the pulley, the inclined plane, the wedge, the wheel and axle, and the screw, all exemplify this interchange of a smaller mass moving with greater speed into a larger mass moving with less speed.

There are, however, many other arrangements serving the very same purpose and equally meriting the name of *mechanic powers.* One of the most notable of these is the *Hydrostatic press*, which will be described in the section on "Hydrostatics."

255. *Oblique action*, the explanation of which belongs to the theory of resolved forces already given in p. 57, is another mode of connecting different velocities. This is exemplified by the *knee-joint*, *knuckle-joint*, or *toggle-joint*, represented in skeleton form in fig. 52, and often employed in machinery where a very great pressure has to be exerted through a small space, as in punching, or shearing iron, or in the printing press, where the types have to be powerfully pressed against the paper.

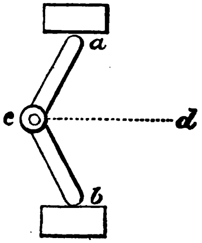

Fig. 52.

In the figure, *c a* and *c b* represent two links or rods, hinged together like a carpenter's folding rule. By force applied to the joint, the two links will be straightened or carried towards *d*.

But the motion of *c* is much more rapid than that of the ends, *a* and *b*; consequently, the outward pressure on the confining guides or obstacles will be correspondingly increased. This is the principle of the *Stanhope lever*, introduced in the end of last century by Lord Stanhope in his improvement of the printing press.

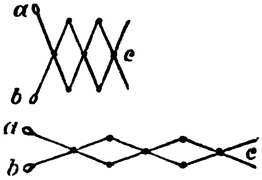

Fig. 53.

256. The arrangement of cross-jointed rods or wires, represented in fig. 53, and called the *Lazy-tongs*, connects different velocities, and therefore different intensities of force. It has been applied to some curious purposes, but to none of much utility. By pressing the ends *a* and *b* towards each other, the rods, from being in the condensed position represented in the upper figure, immediately assume the outstretched position represented in the lower; so that the end, *c*, darts forward much farther and faster than the ends *a* and *b* approximate.

257. (ii.) The *cumulation* of a series of separate motions, impulses, or donations of Energy is often an important means of procuring either increased *intensity* or *volume* of mechanical Energy. This is effected at the expense of *time*, and there is, of course, no creation of mechanical force; yet such *cumulative contrivances* have, according to the old notion, some claim to be considered mechanic powers.

Of this class of machines are *hammers*, *clubs*, *pile-engines*, *battering-rams*, *slings*, *brakes*, *fly-wheels*, &c., all of which admit of the storage of a continued moderate effort being applied in a condensed form to overcome a resistance with which the unaccumulated effort would be totally unable to contend.

A man may have a purpose to effect which a very forcible downward push would accomplish; but, being too weak to give that push directly, he may employ a certain time in carrying a weight to such an elevation above his work that, when let fall. its momentum may do what is required. Thus, the continued effort of a man may be employed to lift a weight to a height of perhaps thirty feet, which may suffice to drive a pile or stake into the earth one inch.

By swinging a sling round and round the head, such a velocity of the stone is accumulated that, when the central constraint is released, it may be projected a long distance.

Brakes, though they are *opposed* to what are usually regarded as powers, are really the same in principle. When a brake is applied to the wheels of a railway carriage moving down an incline or approaching a station, the moving force of the whole train is gradually transferred and accumulated as a minute quiver of the particles of the brake.

The *fly-wheel*, which has often been ignorantly accounted a positive power, in common cases merely equalizes the effect of an irregular force. In using a winch to turn a mill, for instance, a man does not act with equal force all round the circle; but a heavy wheel fixed on the axle moderates the irregularity of speed, by receiving or absorbing momentum while his action is above par, and returning that momentum while his action is below par—thus equalizing the movement. In the common instances of circular motion produced by a crank, as when by the pressure of the foot on the treadle, a lathe, or grindstone, or spinning-wheel, is turned, the force is applied during a small part only of the revolution, in the form of interrupted pushes; yet the motion goes on steadily, because the turning grindstone, or wheel, or lathe, becomes a fly and reservoir, equalizing the effect of the force. The alternate upward and downward pushes of the piston of a steam-engine are converted, by means of a heavy fly-wheel, into a steady rotatory motion.

A heavy wheel is, moreover, often used as a concentrator of force or a mechanic power, in the sense that motion or momentum being gradually accumulated in the wheel, may be made to expend itself in producing some sudden and proportionally intense effect. Thus a man may lift a very heavy weight by first in any way imparting motion to a fly-wheel, and then suddenly hooking a rope from the weight to the axle of the wheel, which rope being wound round the axle, lifts the weight.

A fly-wheel, containing the result of a man's action during perhaps one hundred seconds, when made to impel a screw-press, will, with one blow or punch, convert a piece of smooth metal into a perfect medal or coin; or will, by repeated blows, change a flat piece of silver into a graceful spoon or other utensil.

In the same way a spring may become a mechanical power. A person may expend some minutes in bending it, and may then let fly its accumulated Energy in an instantaneous blow. A gun-lock shows this on a small scale. The slow bending of a bow, which afterwards shoots its arrow with such striking velocity, is another instance.

258. (iii.) A modification of motive Energy, as to *direction* simply, is often an important means to mechanical ends.

It is this power of changing the direction of motion, added to the power of connecting and adjusting different intensities of force and resistance by the simple machines just described, that has enabled man to make complex machines rivalling in their performances the nicest work of human hands. It would be endless to enumerate the various modes in which the direction of motions may thus be changed, for it would be to enumerate and describe the whole apparatus of the arts and sciences.

We shall merely advert to a few as specimens :—

" *Straight motion changed into Rotatory.*"

259. In utilising the Energies of nature—such as a waterfall, or a flowing river, or any falling heavy mass, or the force of the wind, or the Energy of heat expanding steam or air—the storage of the rectilinear force is effected by converting it into a rotatory motion of a heavy wheel, from which, by a series of connected parts, the motion is ultimately obtained in the desired form.

The force of the wind or water may be made to act directly at the circumference of a suitable wheel, and thus pass at once into an Energy of rotation.

The alternate rising and falling of the piston of a steam-engine is made by means of a crank to turn the great fly-wheel, from which the motions of all the other parts are derived.

The crank is the regular contrivance by means of which a series of interrupted straight pushes or motions is converted into rotation, as is seen when the human foot acts on a treadle turning a grindstone, a lathe, or a sewing-machine.

" *Conversion of rotatory motion.*"

260. As the steam-engine is the principal and the type of the so-called mechanical *Prime Movers*, the general problem which the science of *mechanism* has to solve is—

> Given a uniformly rotating heavy mass, such as a fly-wheel, to find the construction and connection of solid parts that shall reproduce this motive Energy in any required form.

If the required form be another circular motion—as for the grinding of corn or the sawing of timber—the motion of the fly-wheel is conveyed by *rolling contact*—that is, by trains of wheels serrated or toothed on the edge, or else by endless bands or cords. This method is of constant application in all kinds of mill-work, where by means of toothed wheels the direction and rate of motion may be changed to any extent ; a horizontal rotation being converted into a vertical, and the slow, steady motion of the fly-wheel being converted into the deafening rattle of hundreds of smaller wheels.

261. If the rotatory Energy of the prime mover has to be reproduced as a rectilinear movement, this may be effected by the *crank*-contrivance, or by the modification of it called an *eccentric*, or by a toothed wheel gearing into a toothed bar or rack, or, most simply, by merely winding a flexible chain or rope on an axle, as in raising water or minerals from a depth.

The conversion of a rotatory into a *perfectly* straight or rectilinear motion by rigid connections is, however, not so easy as may at first sight appear; and, as it is a frequent and an important requirement in machines, a great amount of ingenuity has been expended in the attempt to solve the problem of a *perfectly straight* or *parallel* conversion of circular motion. The difficulties of the case may appear from the following example:—

262. Suppose that we have to work a pump, P (fig. 54), with a steam-engine. The rotatory power is applied by means of the crank, C, to the rod, A, of the piston of the pump. Clearly, as the crank turns, the top, A, of the piston-rod will be moved from side to side, producing a useless straining and irregularity of action. The difficulty may be met, so far, by confining the piston-rod within guides on each side, the straining being then expended in friction against these guides, which will consequently get worn in course of time and cease to be true guides to straight motion.

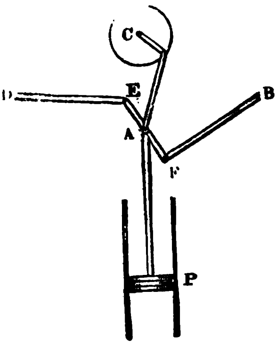

Fig. 54.

It is found, however, that if the end, A, be jointed to the centre of a bar, or link, E F, connected with two other links, E D and F B, moving round D and B as centres, these links will guide the motion of A, so that it deviates extremely little from the straight line so long as A has but a moderate range. This does away with the disadvantages of a sliding guide; still the parallelism of A's motion is by no means perfect.

263. We are indebted to the illustrious Watt for a much more exact parallel motion, the arrangement having been devised by him for the simultaneous working of two piston-rods, by connecting them with the beam of his steam-engine. Fig. 55 will give a general idea of *Watt's parallel motion.* A B F is the half of the beam of the engine, which moves up and down, describing a portion of a circle round A as a centre. B D E F is a parallelogram of bars or links jointed at the four corners, B, F, E, D. At the joint, D, another bar or link, D C, moveable round C as a fulcrum, is connected with the parallelogram; and as one end, B, of the link, B D, is constrained to describe an arc of a circle round A, and the other end, D, an arc of a similar circle round C, that is, in a contrary direction, there will be some intermediate point, P, of the link, which will incline to neither centre of motion, but will describe a rectilinear path up and down. To this point, therefore, the head of the piston-rod is attached. Geometrical considerations show that there will be another point in the line, A P, produced, which will move exactly parallel to P; and the dimensions of the jointed parallelogram, B D E F, with respect to the beam A B F, are usually calculated so that this second point of parallelism falls at E.

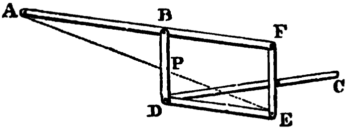

Fig. 55.

Even this motion is but an approximation to a *perfectly* rectilinear one. It is only quite lately that a *really perfect parallel motion*, independent of any gliding guides has been devised.

This is so beautiful in its simplicity that we shall give a general idea of its principle.

"*Peaucellier's exact Parallel Motion.*"

264. Peaucellier, an officer of engineers in the French army, first published, in 1864, his discovery in the form of a question in the '*Annales de Mathématique.*' This exact parallel motion consists of *seven* bars or links connected together and moving, like Watt's parallel motion, round two fixed centres (see fig. 56). Four equal links. P C, C Q, P D, D Q, are jointed together in the form of a diamond; and two other equal arms, C E, D E, are hinged to the diamond corners and move round a fixed centre, E.

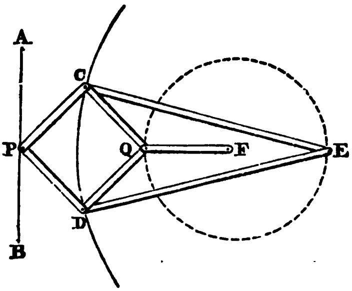

Fig. 56.

It is a geometrical fact that, with these six links or bars so arranged, if the corner or pole, Q, of the diamond be made to describe any curve, the other pole, P, will describe what is called the inverse of that curve; and in general, if Q move in a circle, P will move in a circle also. But, curiously enough, if Q be made to move in a *circle passing through* E (which is easily effected by jointing Q with another link or bar, Q F, whose length is half the distance between Q and E, and moveable about F as a pivot), P no longer moves in a circle, but in a straight line, A B, perpendicular to the line of centres, F E. Thus, a rotatory movement (within limits) of the bar, Q F, is converted into a perfectly rectilinear motion of the point P; and in this way an oscillatory movement of the arm, Q F, becomes a perfectly straight alternate movement of the joint P.

The long-sought-for perfect parallel motion, without guides, has thus been obtained.

Important applications of this principle to various constructions in machinery—such as the steam-engine, planing and polishing machines, millwrights' work, &c.—have already been proposed and even carried into operation.

265. Lastly, continuous circular motion may be converted into a reciprocating, or a variable, motion of any desired nature, by the contrivance known as a *cam*. This is a plate with a curved edge or groove, which communicates motion to another piece pressing against its curved edge.

Fig. 57 represents a heart-shaped cam, which is of frequent employment in mechanism. The up and down motions of the steel punch in a punching machine are regulated by a cam of this description; the punch is thus brought down on the plate with the needed velocity at the proper instant, while by the wheel falling into the hollow of the cam, it is kept raised for a sufficient length of time to allow the workman to shift the plate for the punching of another hole.

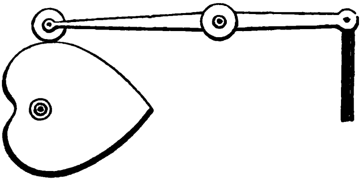

Fig. 57.

In printing-machinery, the extreme precision required in the motions of the sheets of paper is insured by the employment of cams; and the delicacy and rapidity of movement so obtained far surpass the highest efforts of skill which the most practised workman could command.

The pallets or teeth on a turning wheel, which so act on the handle of a great forge hammer, that every one in passing shall lift the hammer and produce a blow, are a simple form of the principle of the cam.

We need not here multiply examples of the thousand artifices employed for the conversion of motion. In this great manufacturing country, with our railways, and steamboats, and power-looms, we are all so accustomed and familiarised with the wonderful results of mechanical inventions, that we have come to regard as very commonplace, what former generations would have looked on as miracles of art.

266. The modification of *mere motion*, without any ultimate reference to the transmission of Energy, is the object of the important class of mechanical contrivances known as *watches*, *clocks*, *chronometers*, &c.

In these the sole aim (see Art. 184) is the production of a perfectly uniform motion, to serve as a *motion-scale* for the measurement of other motions, which, as we have pointed out (Art. 155), is the real meaning of *time*. The inestimable value of such contrivances is too patent to require comment; but it is of interest and importance that we should understand the simple laws upon which their principle depends. As typical of the whole class of such motion-regulators we shall explain the leading features of

" *The Pendulum.*"

We have already seen (Art. 184) that any freely swinging mass may be called a pendulum. Usually it consists of a ball or bob, *a* (fig. 58), suspended by a length of wood or metal from a fixed point, *b*. Now, the most remarkable property of such a body, the discovery of which may be said to have created the art of clockmaking, is its *isochronism;* that is to say, it takes the same time to make a small swing as a large swing (within certain limits). The reason is, that if the pendulum start from *c*, in place of *e* (fig. 58), the beginning of its slope of fall is steeper in the former case, and it will therefore fall the

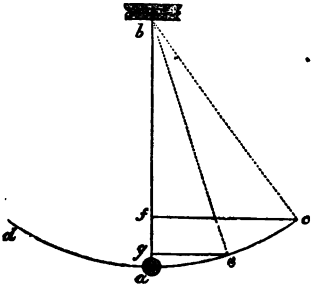

Fig. 58.

faster, and sweep through the larger arc, *c a*, just with proportionally greater speed.

Galileo is said to have discovered this property when a student at Pisa. When in the cathedral there he remarked the singularly uniform vibrations of a chandelier hanging from the roof of the building; and, on comparing the swings with the beat of his pulse, the idea occurred to him that such a simple instrument would be valuable for medical observations on the pulse.

A common clock is merely the application of this uniform vibration of a pendulum to regulate the turning of a wheel, and the consequent motion of a train of wheels, by allowing one tooth of the guiding or *crown* wheel to pass or *escape* for each of its vibrations.

The pendulum is isochronous, however, only so long as its length remains unaltered, for long pendulums swing more slowly than short ones; and clocks (or watches) go slower in summer than in winter, if they be not regulated, owing to the expanding effect of the heat on their governing pendulum (or balance spring).

267. Let us see why this should be so, and what is the exact relation between the length and the time of vibration of any pendulum.

If a pendulum, *b c* (fig. 59), be four times as long as another one, *b d*, it has just four times as far to travel in its descending arc, *c a* as the other in its similar arc, *d e*, while in corresponding parts of the two arcs the slope or inclination is always equal.

The ball of the long pendulum, therefore, may be considered as having rolled four times as far down a given slope as the ball of the short pendulum. Now, a body to fall four times as far, either directly or down any uniform smooth slope, will just take double the time (see Art. 139). Hence the pendulum, *b c*, which is four times as long as *b d*, will just take twice the time to each swing or vibration; and generally, in order that one pendulum may swing two, three, four, five, &c., times as slowly as another, the length of the former must be four, nine, sixteen, twenty-five, &c., times as great as that of the latter.

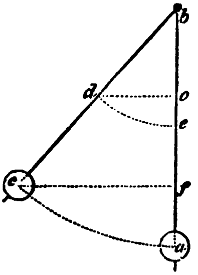

Fig. 59.

A pendulum which vibrates once every second is called a ***seconds pendulum***, which will have an invariable length at any place. For

London the length of the seconds pendulum is a little more than thirty-nine inches (39·13 inches); and it has been proposed that such a measure might be adopted as a universal standard of length.

It is remarkable that the *metre*, or French unit of linear measure, is almost exactly a quarter of an inch longer than the seconds pendulum; but this coincidence is merely accidental, for the metre standard was chosen by the French government in the end of last century, as being the ten-millionth part of the earth's surface measured from the equator to the North Pole through Paris.

For different places on the surface of the globe, however, the seconds pendulum has different lengths, because the power of gravity varies with the distance from the centre of the earth. At the equator, in consequence of the bulging out of our globe there, to beat seconds, the seconds pendulum for London would have to be shortened, and at the poles it would have to be lengthened.

It has, in fact, been found by actual experiment, that a pendulum beating seconds at the equator has to be lengthened by as much as one-fifth of an inch to beat seconds at Spitzbergen. In this way the seconds pendulum may be employed as a means of comparing the intensity of the force of gravity at different places. For a like reason it will be found that a pendulum beating seconds at the level of the sea will beat longer periods when taken to the top of a high mountain; and likewise at the bottom of a mine, where it is attracted by the matter above it, as well as by the matter beneath.

The popular notion that a heavy body falls quicker than a light one (see Art. 135) is confuted by the fact that the time of vibration of a pendulum is unaffected by the weight or material of which it is composed. Equal pendulums of lead, or ivory, or glass, or wood, or iron are all alike in this respect; and a hollow ball vibrates at the same rate, whatever be the nature of its contents—whether air, or water, or mercury.

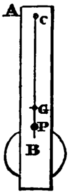

Fig. 60.

It has to be noted, however, that the length of a pendulum is not to be measured by the distance of its centre of gravity, or of its end, from its point of suspension, except in the simple case where the pendulum is a ball hung by a fine thread.

Thus, if from a pin, C, we hang any swinging body, A B, whose centre of gravity lies at G; and if we hang from the same pin a ball, P, by a fine thread, we shall find that, in order that the two may swing together or isochronously, the length of the string, C P, will require to be adjusted somewhere about the position marked in fig. 60. . The corresponding point in A B is called the *centre of oscillation*. It was discovered by the celebrated Dutch philosopher Huyghens that if the pendulum, A B, were now to be suspended from this centre of oscillation instead of its former centre of suspension, it would still vibrate at exactly the same rate as before, and would keep time with the simple pendulum, C P. This property is sometimes called the ***reciprocity or exchangeability of the centres of oscillation and suspension.***

There is a small pendulum called a ***metronome***, used by musicians for marking time; which, although very short, may still be made to beat whole seconds, or even longer intervals. The reason of its slow motion is, that its rod is prolonged upwards, to *b*, beyond its axis of support, at *a*, and has a ball upon the top, at *b*, as well as on the bottom, at *c*. This upper ball prevents the under one from moving so fast as it otherwise would, just as a smaller weight attached to one end of a weighing-beam, prevents a greater weight attached to the other end from falling so fast as it would if there were no counterpoise. The rod, *a b*, is marked with numbers corresponding to the number of beats made per minute when the ball, *b*, is moved to that number.

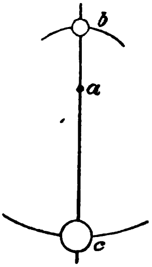

Fig. 61.

“*Friction.*”

268. In estimating the effects of machines by the rule of the comparative velocities of the power and resistance, an important deduction has to be made, on account of the friction between the moving parts. Thus in some forms of steam-engine, where the rubbing parts are numerous, the loss from friction may amount to one-third of the whole Energy applied to the machine.

Friction seems to arise from a decree of adhesive attraction between the touching substances, and from the roughness of their surfaces, even where, to the eye, they appear smooth.

The roughnesses, or little projections and cavities, especially in two pieces of the same substance, mutually fit each other, as the teeth of similar saws would, so as to allow the bodies in a degree to enter into each other; hence the friction is greater between such than between different substances having dissimilar grain.

The friction of one piece of iron, wood, brick, stone, &c., on another piece of the same substance, is measured by using the second piece as an inclined plane, and then gradually lifting one end of it until the upper mass begins to slide—the inclination of the plane, just before the sliding commences, being called the *angle of repose.* This angle, different for different substances, is found to be, for metals, generally such as to mark that the force required to overcome the friction between small pieces of them is equal to about a fourth of the weight of the moving piece; for woods, it is about a half. But for large pieces or for great pressures, the friction is proportionally less.

269. The adjoining fig. 62 exhibits to the eye the different angles of repose for different materials, giving the extreme values of the angle as determined from a large number of experimental observations.

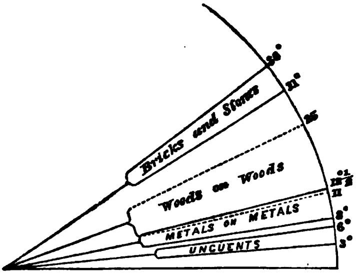

Fig. 62.

It is this angle in the substances concerned which determines the degrees of acclivity, or the slope which becomes permanent in the sides of hills composed of sand, gravel, earth, &c., and in the banks of canals, rivers, water reservoirs, &c.

If the thread of a screw winds round the spindle with an angle less than this, the screw can never recoil, or slide back, from force acting against its point.

270. But for friction, men walking on the ground or pavement would always be as if walking on ice; and our rivers, that now flow so calmly, would all be rapid torrents. It is friction which retains all loose objects on earth in the situations in which for convenience men choose to place them—the furniture of a house, the contents of libraries, museums, &c. Friction is therefore essential to our existence.

Friction it is which enables men, out of the comparatively short fibres of cotton, flax, or hemp, to form lengthened threads, cordage, webs, &c.; for friction alone, consequent upon the mutual pressure of the interwoven and twisted fibres and threads, keeps the material of all these fabrics together.

The Mechanical Laws of Friction.

271. There are three principles that govern the amount of friction between two plane surfaces, one being fixed and the other sliding over it. They have been confirmed by innumerable experiments.

First, *the friction is exactly proportional to the pressure between the sliding surfaces.*

Thus, if we have a number of similar bricks, and it take a certain force to slide a single brick over any surface, that force will have to be doubled or tripled to overcome the friction, when we lay a second or a third brick on the top of the first.

Second, *the friction is independent of the extent of surfaces in sliding contact.*

Thus, to take the case of the brick, the same force will be required to overcome the friction of a single brick, whether we lay it on its broad face, or on its side, or on its edge.

This law is contrary to what we might be inclined at first sight to allow.

Third, *the friction is independent of the relative velocity of the sliding surfaces.*

The frictional resistance to be overcome in moving a railway train or a sledge is quite the same, whether the motion be swift or slow; being dependent solely on the nature of the surfaces in contact and the load which presses them together.

272. It is to be remembered, however, that the friction to be overcome in *first moving* one surface over another, is much greater than when the motion is once begun. After surfaces have been some time in contact, the increase of frictional resistance may be very considerable, and is very uncertain.

Vibrations of surfaces in contact also diminish the frictional adhesion. Thus the carpenter, by a single blow on the end of his plane, loosens the wedge which keeps the cutting-iron firmly in its place.

Wheel carriages, in travelling over rough roads or pavements, are apt to have their nuts loosened by the lessening of the frictional adhesion between the nuts and the surfaces on which they are screwed down.

Hence in carriages, and in all machinery which is subject to considerable vibration, this slipping of the nut has to be prevented by adding another nut, screwed hard down upon the first.

273. But friction, which is so essential to our existence and to the construction of a piece of machinery, is also a serious cause of waste of Energy in its transmission through any machine. In practice the relation between the Energy applied as the power to a machine and the Energy recovered as work, differs considerably from what is deduced by the theoretical considerations such as we have given for the lever, the pulley, &c.; and the practical man knows the allowance to make for frictional waste of Energy in each case. However perfectly a machine may be constructed, this waste is always a very appreciable fraction—sometimes as much as a fourth, or a third, or a half, or even more—of the Energy applied; and the *efficiency* of a machine depends, therefore, on the means employed to avoid this useless waste.

274. The following means are employed to diminish friction between rubbing surfaces, and are used singly or in combination, according to circumstances.

1. Making the rubbing surfaces smooth.

2. Interposing some lubricating substance between the rubbing parts; as oils for the metals; soap, grease, black-lead, &c., for the woods.

3. Letting the substances which are to rub on each other be of different kinds. Axles are made of steel, for instance, and the parts on which they bear are made of gun-metal or brass: in small machines, as time-keepers, the steel axles often play in agate or diamond. The swiftness of a skater depends much on the great dissimilarity between steel and ice.

4. Using wheels, as in wheel-carriages, instead of dragging a solid mass or sledge along the ground. This is a contrivance of very great antiquity. Castors on household furniture are miniature wheels.

5. Placing the thing to be moved on rollers, as is commonly done when a log of wood or a heavy package is drawn along the ground upon smaller round pieces; or when a heavy cannon, with a flat circular base to its carriage, is turned round by rolling on loose cannon-balls having a hard level bed.

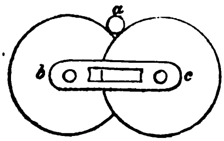

Fig 63.

6. Using what are called friction wheels, or rather *anti-friction* wheels; which still farther diminish the

friction even of a small axis, by allowing it to rest on their circumferences, which turn with it. In fig. 63, *a* represents the end of an axis, resting on the rims of two friction wheels, *b* and *c.*

Of all rubbing parts, the joints of animals, considering the strength, frequency, and rapidity of their movements, are those which have the least friction. The rubbing surfaces in these are covered, first, with a layer of elastic cartilage, and then with an exceedingly smooth membrane, over which there is constantly poured from surrounding glands a fluid called synovia, more emollient and lubricating than any oil, and which is renewed constantly as required. We study and admire the perfection of animal joints, without being able very closely to imitate them.

275. *Wheel carriages* illustrate many of the circumstances connected with friction. They have three advantages over the ancient sledges for which they are the substitutes :

1. The rubbing or friction, instead of being between an iron shoe and the stones and irregularities of the whole road, is between the axle and its surrounding bush, of which the surfaces are smoothed and fitted to each other, and well lubricated.

2. While the carriage moves forward, ten or fifteen feet, by one revolution of its wheel, the rubbing part, viz., the axle, slides over only a few inches of the internal surface of its smooth greased bush.

3. The wheel instead of butting against any abrupt obstacle on the road, surmounts it by the axle describing a gentle curve over it,—as shown in fig. 64, where *a* represents an obstacle, and where the curve from *c*, of which the beginning has the direction shown by the line *c e*, represents the path of the axle in surmounting it. The wheel is as if rising on an inclined plane, and gives to the drawing animal the relief which such a plane would bring. The advantage is greater in a large than in a small wheel, for the smaller wheel, in having to surmount more quickly the same size of obstacle, *b*, has to rise in the shorter and steeper curve beginning at *d*. Again, a small wheel will sink to the bottom of a hole or

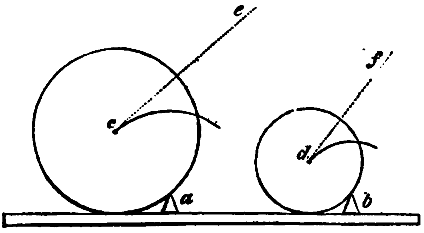

Fig. 64.

depression in the road, where a larger one would rest on its edges as a bridge, and would sink less.

The fore-wheels of carriages are usually made small, to facilitate the turning, by their passing under the body of the carriage. It is not true, however, according to the popular prejudice, that the large hind-wheels of coaches and waggons help to push on the little wheels before them, as if the carriage were on an inclined plane; but there is the accidental advantage, that in ascending a hill, when the horses have to put forth their strength, the load rests chiefly on the large hind wheels, and in descending, when an increased resistance is desirable, the load falls chiefly on the smaller fore-wheels.

276. The wheel of a carriage, simple as, from our extreme familiarity with it, it now appears to us, is a thing of very nice workmanship, and has exercised much ingenuity. It possesses marvellous strength, somewhat of the nature of that of the arch, from what is called its *dished* form, seen in the wheel *c d* (fig. 65), as contrasted with the flat wheel, *e b*. In a wheel of this form, the extremity of a spoke cannot be pressed or strained inwards, or towards the carriage, unless the rim of the wheel be diminished; and it cannot be displaced outwards, or away from the carriage, unless the rim be enlarged; now the rim being bound by a strong ring or tire of iron, cannot suffer either increase or diminution, and the strength of all the spokes is thus by it compelled to aid each individually. In a perfectly *flat* wheel a given degree of displacement outwards or inwards of the extremities of any one spoke, is not resisted by the strength of all the others. A dished wheel is stronger than a flat wheel, for the same reason that a watch-glass and a round piece of egg-shell are stronger than flat pieces of like thin substances.

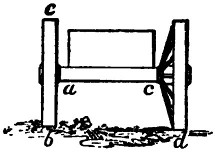

Fig. 65.

277. The application of springs to carriages, which is an improvement of comparatively recent date, not only renders them soft-moving vehicles on rough roads, but much lessens the pull to the horses. When there is no spring, the whole load must rise with every rising of the road, and if time be given, must sink with every depression, and the depression costs as much labour as the rising, because the wheel must be drawn up again from the bottom of it: but in a spring-carriage moving rapidly along, only the parts below the springs are moved in correspondence with the road-surface, while all above, by the inertia of the matter, have a comparatively soft and even advance. Hence arises the superiority of those modern carriages, furnished with what are called *under-springs*, which insulate from the effect of shocks, all the parts, excepting the wheels and axletrees themselves. When only the body of the carriage is on springs, the horses have still to rattle the heavy framework below it over all irregularities, and then the wheels, as well as the structure generally, require to be of much greater strength and weight to bear the consequent shocks. But for this contrivance of springs, our modern railway-travelling would be much less luxurious than it is.

Even all the improvements previously made in regard to roads and carriages, appear of small significance in comparison with what British ingenuity and enterprise have achieved through the iron railway, with its locomotive engine or steam-horse. By these, men now travel and transport heavy loads, at a rate exceeding forty or even fifty miles an hour, equalling the speed of a bird's flight or of a strong wind! Many regarded the scheme, when first proposed, as an impracticable dream.

278. Influence of Magnitude, Form, and Position on the Strength of Bodies and Structures.

The practical engineer has to consider not only the geometrical forms and shapes to be given to the different parts of a mechanical combination for the particular modification of motion he may require; he has also to calculate the forces and strains which will be brought to bear on the different pieces of the mechanism, and to adapt the strength of the various parts accordingly. To the mechanic and engineer the study of the strength of materials is thus of the highest importance.

A knowledge of the natural properties of the materials he uses—especially of the different woods and metals—is obviously an essential part of such study. For the details of this branch of the subject, which belong to the practical engineer, reference must be made to special treatises, such as Dr. Anderson's work on the Strength of Materials, &c. Here we shall be content with some of the general principles, which should be familiar to everybody.

279. *Of similar bodies the largest is proportionally the weakest.*

Suppose two blocks of stone (fig. 66) projecting from a hewn rock, or a strong wall, one, *d*, twice as long and deep and broad as the other, *b*, and therefore with eight times as much substance in it. The larger one will by no means support at its end as much more weight than the smaller, as its mass is greater, and for two reasons. 1st. In the larger, each particle of the surface of attachment at *c*, in helping to bear the weight of the block itself, has to support by its cohesion twice as many particles beyond it in the double extent of projection, from *c* to *d*, as a particle has to support, in the shorter block at *a*, from *a* to *b*; and, 2ndly, both this additional mass and anything appended at its outer extremity, are acting with a double leverage to destroy the cohesion at *c*. Hence it follows, that if any such mass be made to project very far, it will be broken off by its own weight alone.

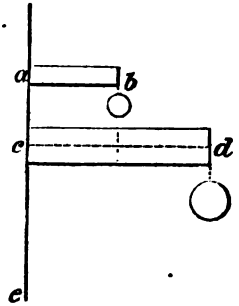

Fig. 66.

What is thus true of a block supported at one end, is equally true of a block supported at both ends, and indeed of all masses, however supported, and of whatever forms, if they have projecting parts. Perpendicular masses, like cliffs on the sea shore, which have no projecting or overhanging parts, are still limited as to size by the degree of cohesive force among their particles, for the upper part of such a mass tends to crush or break down the lower. A lofty pillar cannot be formed of soft clay, and a wall of the hardest brick would crush the bottom layers to dust before it reached the elevation of a thousand feet.

That a large body, therefore, may have proportionate strength to a smaller, it must be still thicker and more clumsy than it is longer; and, beyond a certain limit, no proportions whatever will keep it together in opposition merely to the force of its own weight.

280. This principle limits the size and modifies the shape of most productions both of nature and of art;—of hills, trees, animals, architectural or mechanical structures, &c.

281. *Hills.*—Very strong or cohesive material may constitute hills of sublime elevation, with broken cliffs and precipices nearly perpendicular; and such accordingly are seen where the hard granite protrudes from the bowels of the earth, as in the Alps of Europe, the Andes of America, and the Himalayas of Asia. But material of inferior strength exhibits more humble risings, and more rounded surfaces. The gradation is so striking and constant, from mountains of granite down to those of chalk, or gravel, or sand, that the geologist can often tell the substance of which a hill is composed merely by observing the peculiarities of its shape.

The grotesque figures of rocks and mountains seen in the paintings of the Chinese, or actually formed in miniature for their gardens, to express their notions of the picturesque and sublime, are caricatures of nature for which exact originals can never have existed. Some of the islands in the Eastern Ocean, however, and some of the mountains of the chains seen in a voyage towards China, along the coasts of Borneo and Palawan, and Manilla, which the author, in passing along, had the opportunity of sketching, exhibit the very limits of possibility in singular shapes. In our moon, where the weight or gravity of bodies is less than on earth, because of her smaller size, mountains of a given material might be much higher than on earth; and astronomers have found that the lunar mountains are in fact very high in proportion to the mass and diameter of the moon.

By the action of winds, rains, currents, and frost, upon the elevated masses around us, there is going on unceasingly an undermining and wasting of supports, so that every now and then portions are torn, by gravity from elevated stations to sink to lower levels, in obedience to the law now explained.

282. *The size of vegetable growths* is obedient to the same law. There are no trees reaching a height of more than three hundred feet, even when perfectly perpendicular and sheltered in forests that have been unmolested from very remote antiquity: and oblique or horizontal branches are kept within comparatively narrow limits by the great strength required to support them. The truth that, to have proper strength, the breadth or diameter of bodies must increase more quickly than the length, is well illustrated by the contrast between the delicate and slender proportions of a young oak or pine in the seedsman's nursery, and the sturdy form of one that has braved for centuries all the winds of heaven.

283. *Animals* furnish interesting illustrations of the same law.

How massive and clumsy are the limbs of the elephant, the rhinoceros, the heavy ox, compared with the slender forms of the stag, antelope, and greyhound! And unless the bones were made of stronger material than now, an animal much larger than the elephant would be crushed to the earth by its weight alone. The whale is the largest of animals, but feels not its enormous weight, because lying continually in the liquid support of the ocean. A cat may fall with impunity from a greater height than would suffice to dash the bones of an elephant or of an ox to pieces.

For the reason which we are now considering, the giants of the heathen mythology could not have existed upon this earth. In the planet Jupiter, which is many times larger than the earth, a man made as we are would be carrying in the simple weight of his body a load several times greater than he bears here. The phrase, *a little compact man*, points to the fact that such a person is stronger in proportion to his size than a taller man.

284. The same principle limits the height and breadth of architectural structures. In the houses of fourteen stories, which formerly stood for protection close under the guns of the castle of Edinburgh, there was danger of the superincumbent wall crushing the foundation.

Roofs.—Westminster Hall approaches the limit of span which, wood being used as the material, is attainable without very inconvenient proportions or central supports.

Arches of a bridge.—A stone arch, much larger than those of the magnificent bridges in London, would be in danger of crushing or splintering its material by the horizontal thrust of its mass.

Ships.—A ship's yard, ninety feet in length, contains twenty times as much wood as a yard of thirty feet, and even then is not so strong in proportion.

Since, within the present century, iron, because of its stronger cohesion has been substituted for wood and stone in the construction of roofs, domes, bridges, ships, &c., vastly greater dimensions are attainable in all.

"*Strength of Columns.*"

285. In *longitudinal compression*, as produced by a body, *a*, on the support, *b* (fig. 67), the weight can destroy the support, while it remains straight, only by crushing. And a very slender column, if kept perfectly straight, supports a very great weight. But if the pillar be originally crooked, or begins to bend, as *c d*, the strain, is one of crushing on the concave side of the column, and tearing asunder on the convex side; and everything depends on the strength of the superficial layer of the column to withstand these opposite forces. The substance near the centre in such a case is little affected, and might be absent without the strength of the pillar being much lessened.

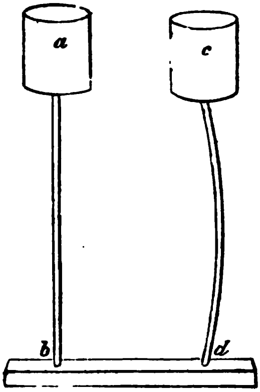

Fig. 67.

286. Long pillars or supports are weaker than short pillars of the same diameter, because they are more easily bent; and they are more easily bent because a very inconsiderable, and therefore easily effected, yielding between two adjoining particles makes a considerable bend in the whole; while, in a short pillar, there cannot be much bending without a great change in the relation of proximate particles and such as can be effected only by great force. The weight resting on any pillar, and bending it, may be considered as acting with a leverage reaching from the extremity to the centre of the pillar, against the cohesive strength resisting with a leverage reaching from the side of the pillar to its centre. The strength of the pillar will therefore depend on the relation between these leverages. Thus shortness, or a lateral stay, such as *a e b* (fig. 68), which, by increasing the resisting leverage, opposes bending—really increases the strength of a pillar.

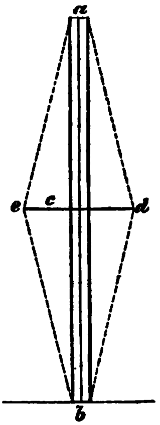

Fig. 68.

A column with ridges projecting from it, is on this account stronger than one that is perfectly smooth.

A hollow tube of metal is stronger than the same quantity of metal as a solid rod, because its substance standing farther from the centre resists bending with a longer leverage. Hence pillars of cast iron are generally made hollow, that they may have great rigidity and strength with as little metal and weight as possible. The interior is usually filled with brick, stone, and other materials connected together.

In delicate philosophical balances the arms are hollow cones of brass, in order that the least possible weight may be combined with the greatest strength.

Masts and yards for ships, and the jibs of cranes for raising enormous weights, are now made of iron, and hollow, in accordance with the same principle.

Illustrations of this principle are common in nature.

287. The stems of many vegetables, instead of being uniformly round externally, are ribbed or angular and fluted, that they may have strength to resist bending. Many also are hollow, as cornstalks, the elder, the bamboo of tropical climates, &c., thereby combining lightness with wonderful strength. One who has visited the countries where the bamboo grows, cannot but admire the almost endless uses among the inhabitants which its straightness, lightness, and hollowness fit it to serve. Being found of all sizes, it has merely to be cut into pieces of the lengths required for special purposes, and Nature has already been the turner, and the polisher, and the borer, &c. On many of the shores and islands of Eastern Asia it is the chief material, both of the dwellings and of the furniture; there are the bamboo huts and bungalows, containing their bamboo chairs, couches, beds, &c.; flutes and other musical instruments there, are merely pieces of the reed with holes bored at the requisite distances; conduits for water are pipes of bamboo; bottles and casks for preserving liquids are single joints of larger bamboo with the natural partitions remaining; and bamboo split into threads is twisted into rope, &c.

From the animal kingdom also we have numerous illustrations of our present subject:—as in the hollow stiffness of the quills of birds; the hollow bones of birds; the bones of animals generally, which are strong and hard, and often angular externally, with light cellular texture within, &c.

Transverse Strength.

288. When a beam is laid horizontally and supported at its extremities, *a*, *b* (fig. 69), its weight alone bends it more or less perceptibly; and the bending and tendency to break will be greater according as the beam is longer and its thickness or depth is less.

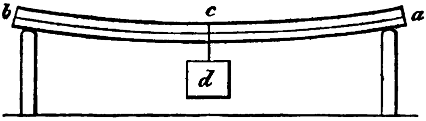

Fig. 69.

As the upper or concave layer of molecules is compressed, while that on the lower or convex side is distended, it is obvious that there will be some intermediate line or layer, *a b*, where the particles are unaffected by either compression or distension. This line is called the *neutral line*, or axis of the beam.

The breaking strain in such a beam is estimated by considering the weight of the beam, and the load it bears as a force acting at the centre with a leverage reaching to the end of the beam; while the resistance is, the force of cohesion on the lower face with a leverage extending to the neutral line, and the resistance to crushing in the upper face with a leverage reaching to the same line.

If either of the latter resistances be unequal to the former force the beam must give way. Also, since the resistance of materials to crushing is in general very great—far greater than their resistance to extension—the strength of a beam will mainly depend on the cohesive strength of the lower or convex face of the beam. This last circumstance is so remarkable that the scratch of a nail on the under side or skin of a plank resting as here, will sometimes suffice to begin the fracture; while the beam may be sawn half through from above without losing its strength.

It is because the strength of a beam depends conjointly on its thickness or area of cross-section, and on the distance of its upper and lower faces from the neutral axis, that a beam or plank has far greater strength when placed on its side than when laid with its broad face down. A slip of glass—such as is used for mounting microscopic objects—may easily be broken the one way, but will, require enormous pressure to break it across the other way.

289. In modern times iron beams, called *girders*, are employed where, as in railway bridges, or warehouse flooring, great loads have to be borne. These are not only less clumsy in appearance than the great wooden beams formerly employed, but, when their dimensions are properly adjusted, they are much more secure. The tenacity of iron is so enormous (16,000 lbs. per square inch of section), that there is scarcely a limit to the size and strength which girders may be made to possess, if constructed with a due regard to mechanical principles.

These cast-iron beams or girders are now made, not in the shape of a common uniform wooden plank, but having a cross section similar to that shown in fig. 70, as will be seen in the case of the girders supporting any of our railway bridges. The discovery of the proper shape to be given to such beams, in order that they may have uniform strength was of great value, as effecting great saving of material, besides diminution of stress on the beam arising from its own weight.

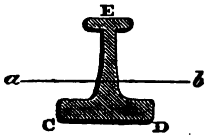

Fig. 70.

Cast-iron resists crushing with about six times the force that it resists tearing asunder. Thus the upper flange, E, of the beam need be only one-sixth the size of the lower flange, C D, to have equal strength with it: and any additional material adds merely to the weight of the beam without increasing its strength. The two flanges are connected by a deep, thin, vertical piece or *web*, which, for the reason already given, possesses great power of resistance to transverse fracture.

290. By giving the tubular or hollow form to a beam, lightness may be combined with strength to a surprising degree. The celebrated engineer, Fairbairn, was the first to attempt this form of beam on a large scale. A gigantic square-cornered tube, built up of wrought-iron plates riveted together, stretches across the arm of the sea between Wales and Anglesea, and is so strong that railway trains *pass through it at full speed* with perfect security. The central portion is 600 feet long, and is supported only at the extremities. The complete success of this piece of engineering art has established the truth of the theoretical principles assumed in its construction.

The Strength of the Arched Form.

291. If a transverse beam, instead of being horizontal, were shaped as an arch, a little consideration will show that a load would act by *compression both on the upper and on the under side of the beam.* Thus the force of cohesion is not called into play at all, but only the resistance to crushing. Hence, too, if a series of loose bricks, having no cohesion, be thrown into the arched form, and rest against immovable abutments, as in this fig. 71, the weight of the bricks and any load placed on them will merely tend to crush the bricks against each other; and it will take a load greater than the crushing strength of the material to make the arch give way.

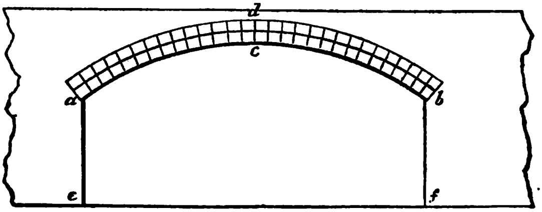

Fig. 71.

An error frequently committed by bridge-builders, is the neglecting to allow sufficiently for the effect of the horizontal thrust of the arch on its piers. The weight of each arch produces an oblique thrust (see Art. 255), pushing the pier away from it. In some instances, one arch of a bridge falling, has allowed the adjoining piers to be pushed down towards it by the thrust, no longer balanced, of the arches beyond, and the whole structure has given way at once like a child's house or bridge built of cards. A bridge showing these defects of structure is to be seen on the Tiber, in Rome. It is, in fact, only half a bridge, and is known under the name of the *Ponte Rotto.*

It is not known at what time the arch was invented, but it became common only in comparatively modern times. The hint may have been taken from nature, for there are instances in Alpine countrie of natural arches, where rocks have fallen between rocks, and have there been arrested and suspended, or where burrowing water has at last formed a wide passage under masses of rock, leaving them balanced among themselves as an arch above the stream. Nothing can surpass the strength and beauty of some modern stone bridges; —those, for instance, which span the Thames as it winds through London.

Arched bridges of iron have been made with spans twice as wide as those of stone: the material being more tenacious and easily moulded, is calculated to form a lighter whole. The bridge of three such arches built in 1819, between the City of London and Southwark, is a noble specimen; and, compared with those erected in the preceding century, appears almost a fairy structure of lightness and grace.

The great domes of churches and cathedrals owe their strength to the same principles as simple arches. They require to be strongly bound at the bottom with iron bars, or otherwise, to counteract the horizontal thrust of the superstructure.

The Gothic arch is a pointed arch, and is calculated to bear the chief weight near its summit or key-stone. Its use, therefore, is not properly to span rivers as a bridge, but to enter into the composition of ornamental architecture, and to carry a great weight of material above it. With what effect it does this, is seen in the sublime Gothic structures which adorn so many parts of Europe.

The following are instances, in smaller bodies, of strength obtained by the arched form: A thin watch-glass bears a very hard push. The shell of an egg, although formed of a thin layer of brittle chalk, possesses, by reason of its arched form in all directions, considerable strength. It thus forms a wonderful defence of dormant life. A full cask may fall with impunity, where a strong square box would be dashed to pieces. A very thin globular flask of glass, corked and sent down many fathoms into the sea, will resist the pressure of water around it, where a square bottle with sides of much greater thickness would be crushed to pieces.

Railway tunnels, having to bear enormous pressure from without, are constructed of the arched form, in order to resist the superincumbent weight of earth. Water and sewage-pipes laid under the streets of our cities are cylindrical, to resist the pressure of the surrounding earth.

292. We have, in the animal frame, an illustration of the arched form giving strength. The cranium or skull, and particularly the skull of man, which is the largest in proportion to its thickness, by its arched form, combines lightness with secure protection for the extremely delicate brain within.

To determine, for particular cases, the best forms and positions of beams and joists, of arches, domes, and so forth, is a matter of geometrical calculation, often very complicated; it belongs to practical architecture or engineering.

It was a beautiful problem of this kind which Smeaton, the illustrious English engineer of the last century, solved so perfectly in the construction of the far-famed Eddystone lighthouse. He had to determine the form and arrangements of a building to stand firm on a sunken rock—from which preceding structures had been swept away—in the channel of a swift ocean tide, and exposed to the fury of tempests from every quarter. The man who has himself been driven before the irresistible storm amid the darkness and dangers of night, and whose eyes have watched the steady ray from the lighthouse that saved him, cannot fail to appreciate the importance of the knowledge that leads to such precious results, and can judge how wise it would be in governments to promote to the utmost, the study of the natural sciences as a part of general education. The engineer who successfully executes such works as these not only obtains honour and reward for himself, but accomplishes the nobler end of helping to bind the whole human race in one great brotherhood.

PART III.

SECTION I.—HYDROSTATICS, OR THE PHENOMENA OF LIQUID PRESSURE.

ANALYSIS OF THE SECTION.

The particles of a fluid, being freely movable among one another, offer no resistance to separation, and hence their properties differ in many important points from those of solids. Fluids are of two classes; first, those practically incompressible, *called* Liquids; *and, second, those* compressible to any extent, *called* Gases. *The first class is the subject of this section.*

The particles of a liquid (or any fluid) being equally movable in every direction, cannot be affected with pressure at any part, without this pressure being instantly felt at every portion of the liquid; so that a plug or piston forced inwards on a square inch of the surface of a liquid filling a vessel with a force of a pound, instantly produces a pressure of a pound on each square inch of any surface pressed by the liquid, or on every square inch of the surface of any body immersed in the liquid.

The pressure on any immersed surface arising from the weight *of a liquid, depends wholly on the extent of the surface and on the* vertical *depth, and not on the quantity of surrounding liquid. Thus the pressure on the base or bottom of a vessel may be either equal to, greater than, or less than the weight of its liquid contents—a fact which is usually called the* hydrostatic paradox.

The open or free surface of a liquid is horizontal: and when various pipes or vessels communicate with each other, water or any other liquid will rise to the same level in all.

A body wholly or partially immersed in a liquid (or fluid) is buoyed up with force equal to the weight of the displaced liquid, and will therefore sink or swim according as its own weight is greater or less than this. The relation between the weight of any body and that of the water it displaces, is the estimate of its SPECIFIC GRAVITY *compared with water, as a standard.*

"*Fluid.*"

293. The very same matter may, as has been already explained, exist in the form of a solid, a liquid, or a gas. A pound of ice, a pound of water, and a pound of steam differ only in the mutual distance of the particles, due to the different quantities of heat-motion existing among them.

In the ice they are comparatively near, and are as it were spitted or glued together by cohesion ; in the water, the repulsion of heat seems almost to balance this attraction, and to leave the particles at liberty to *flow* or glide about among each other almost without friction ; and in the steam this heat-repulsion altogether overcomes the attraction, the particles are separated to a great distance, and, as we have reason to suppose, are in incessant commotion.

A body in either the liquid or the gaseous state is called a *fluid*, from this mobility or *flow* among its particles. Owing to the common feature of fluidity, there are certain properties belonging alike to liquids and to gases ; but, on the other hand, so important are the differences, that the phenomena of the two conditions of matter must be treated separately.

There are thus two distinct branches relating to Fluids, namely,

(i.) *Hydrostatics* and *Hydraulics*, which treat of the phenomena of liquid pressure and of liquid motion respectively.

(ii.) *Pneumatics* which treats of the phenomena of air and gases.

"*Liquids incompressible.*"

294. In a liquid the particles are so near together that it is only by very great force that they can be pressed closer ; and indeed, until improved means of experiment were recently contrived, liquids were accounted absolutely incompressible. Nor need we wonder that their compressibility escaped detection so long, for a pressure of 3500 lbs., or about 1½ ton, on a column of water a square inch in section would reduce its bulk only by a hundredth part ; and on a similar column of mercury, it would take 13 times as much to effect this degree of compression.

"*Fundamental principle of Liquids.*"

295. *As the particles of a liquid are equally ready to move in every direction, a pressure upon any one portion of the liquid must be equally resisted at all points, in order that the liquid may remain at rest.*

Thus if we were, by means of a pressure of 100 lbs., to force into a cask filled with liquid a plug having a surface of a square inch, ***every square inch of surface*** of the cask must be able to stand this pressure of 100 lbs., otherwise the vessel will burst. And if the cask were three feet in girth, an iron hoop an inch broad running round it must, if the cask depends on its binding, be able to resist a force of 3600 lbs. trying to pull it asunder.

296. In like manner, if a close vessel, B (fig. 72), fitted with a narrow tube, *a c*, be filled with water, and if then, by means of a movable plug or piston in the tube, the water be pressed with a force of one pound, the water throughout every portion of the vessel, B, of equal surface with *c*, will bear a strain or pressure to the extent of one pound. Thus, if there were fitted into the top of the box, B, another similar tube, *b*, also with a plug, a force of one pound depressing *c*, would push up the plug, *b*, with the same force. And if there were any number of similar tubes and plugs, by acting on one, we should equally affect all. Hence a piston of double area would be twice as much affected as the smaller one; and one of ten times the area, such as *d*, would be pressed upwards with a force of ten pounds. Through the medium of a confined fluid, a force of one pound may in this way become a bursting force of ten, or a hundred, or a thousand pounds, according to the size of the vessel, or may be used as a *mechanical power* to increase the *intensity* of a force to any degree. It will be explained below that the *hydrostatic press* is merely a large plug or piston as here described, forced up against the substance to be pressed, by the action of a smaller piston in another barrel.

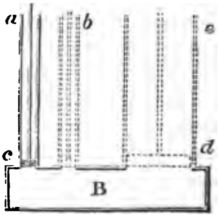

Fig. 72.

The pressure of one pound may be applied by pouring in a pound of water in the tube, *a c*, and the same results will obviously be produced on the plugs in *b* and *d*; and if, in the other tubes also, water were substituted for the pistons, it is evident that, to effect a balance in all, it would require to stand as high in every one as in the tube, *a c*, producing thus the same level in all, whatever their size.

"*Hydrostatic Paradox.*"

297. The fact that the weight of one pound of water, or any other force of one pound similarly applied, may thus be made to produce a pressure of hundreds or of thousands of pounds, has been called the "hydrostatic paradox;" yet there is in reality nothing more paradoxical in it, than that one pound at the long end of a lever should balance ten pounds at the short end. Like the mechanical powers, described in the last section, it is but a means of causing different intensities of force to balance each other, by applying them to parts of an apparatus moving with different velocities. Here the tube, *a*, being ten times smaller than the tube, *e*, the piston in *a* must descend ten inches to raise the greater piston in *e* one inch ; so that, as was explained in the case of the other mechanical powers, there is no increase of force here, but only a translation of a small force moving through a great space, into a great force moving through a correspondingly small space.

Moreover it is to be noticed that, since liquids are practically incompressible and free from friction, there is much less waste of Energy in the transmission of power by their agency. We have in the *hydrostatic lever*, as we may call this, a much nearer approach to absolute rigidity and perfect freedom of motion than in the solid lever moving about a fulcrum.

"*Illustrations of Liquid Pressure.*"

298. This law of fluid pressure is very strikingly illustrated by the bursting of a strong cask with the weight or action of a few ounces of water. Suppose a cask, *a* (fig. 73), filled with water, to have a long narrow tube, *b c*, screwed tightly into its top. The tube can contain only a few ounces of water ; yet these few ounces in the tube may suffice to burst the cask. In explanation, it is unnecessary to say more than that if the tube have an area of a fortieth of an inch, and contain when filled, half a pound of water, that water would produce a pressure of half a pound upon every fortieth of an inch all over the interior of the cask, or of nearly 2000 lbs. on every square foot,—a pressure greater than any ordinary cask can bear.

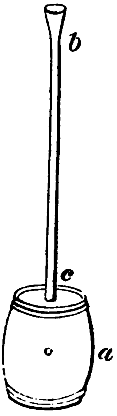

Fig. 73.

299. A similar effect is seen in the toy called the *hydrostatic bellows*. This consists of (fig. 74) two wooden discs, *d*, *c*, (connected as in a common bellows by flexible sides of leather), and a long small tube, *a b*, by which water can be poured to enter the body of the apparatus. If the tube, *a b*, holds an ounce of water, and has itself only one-thousandth of the area of the top of the bellows, an ounce of water in it will balance the weight of a thousand ounces on the top of the bellows at *d*. If mercury were substituted in this machine for water, the pressure of a column of the same height would support just thirteen and a half times as much, because mercury is so many times heavier. A man standing on the bellows might raise himself by blowing into the tube with his mouth, if the difference between the diameters of the tube and the bellows were sufficiently great; though of course, in accordance with the general principle of Energy, the space through which he would raise himself would be correspondingly small.

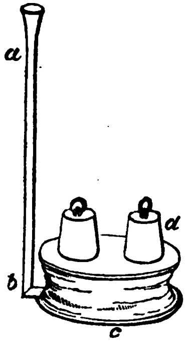

Fig. 74.

300. A remarkable illustration of liquid pressure is seen in the *Hydrostatic* or *Hydraulic Press*, perfected by Bramah in the end of the last century.

The annexed cut (fig. 75) will give an idea of it. Compared with the bellows, it exhibits merely a strong forcing pump, *e*, in the figure, instead of the lofty tube; and a large barrel, *a b*, with its piston, *c f*, instead of the leather and boards. The pump is worked by the handle, *d*, and drives water along the horizontal tube into the space, *f*, under the large solid piston, *c*, which last, with its spreading top, is urged against the object to be compressed. If the small pump have only one-thousandth of the area of the large barrel, and if a man, by means of its lever-handle, *d*, press its piston down with a force of a hundred pounds, the piston of the great barrel will rise with the force of a hundred thousand pounds. Scarcely any resistance could withstand the power of such a press; with it the hand of a child might break a strong iron bar. It is used to condense bulky yielding substances, as cotton or hay, for sea voyages, to raise great weights, to uproot trees, to test the strength of cables, to launch vessels, to insert the axles into railway carriage wheels, to force the oil out of seeds, and for numerous other purposes. The efficiency of the hydraulic press as a mechanical power depends (1) on the *perfect mobility* of fluid particles, which furnishes the means of increasing the intensity of force without practical loss by friction in the course of its trans-

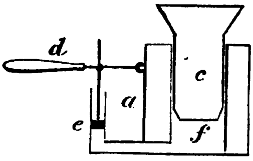

Fig. 75.

mission; and (2) on the *incompressibility* of liquids, for if the space, *e f*, were filled with air or any compressible fluid, a serious loss of Energy would arise, as will be at once perceived.

301. *Liquids have weight; consequently the particles below the surface have to bear the weight of those that are above them: also this pressure, being occasioned by the weight acting vertically downwards, is in proportion simply to the* VERTICAL DEPTH, *and is not dependent on the quantity of surrounding liquid, or on the shape or size of the containing vessel.*

In an upright column or tube of water, it is evident that the weight of water pressing on the bottom, *a* (fig. 76), is doubled when the tube is filled up from *b* to *c*, tripled when up to *d*, and so on. The liquid is supposed to be incompressible; so that the weight of each mass of water-column, of the same height, will be the same and will remain unchanged by the addition of more water above.

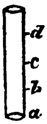

Fig. 76.

We have much greater difficulty in conceiving how the pressure on the bottom may be different from the weight of the liquid; which happens when the vessel is shaped irregularly, as in the adjoining cuts (fig. 77). In the first, the vessel widens out towards the mouth; now a little consideration shows that whatever liquid there is more than the vertical column, A *a*, standing on A, is prevented from falling, that is, has its pressure supported, by the sides A B and A C, of the vessel, and balances the column, A *a*, on all sides round about. So that in reality A has to support only the upright column, A *a*.

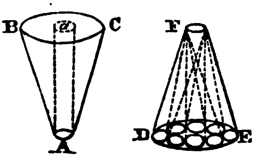

Fig. 77.

In the other case, where the vessel tapers at the mouth, let us suppose the bottom, D E, divided into a number of portions of the same size as the mouth, F, and that there are eight of these portions. It is an immediate consequence of the principle of *equal pressure in all directions*, that the weight of a small liquid mass half-an-inch thick at the top, will be transmitted undiminished to each of the eight portions of the base, and will produce the same pressure there as eight of these masses spread over the bottom. So, again, if we consider a half-inch layer of the liquid lower down, say twice as large as F, it is evident in like manner that its pressure on the whole base will be the same as four layers like itself laid on the base, that is, the same as eight of the upper little layers.

Thus we see that ***each horizontal layer of the same thickness, no matter where it lies in the liquid,*** produces the same pressure, and a pressure depending only on its thickness and the size of the base. Hence the resulting effect of the whole is to produce a pressure depending only on the size of the base and the vertical height of liquid; that is, it is the same as the pressure of an upright column of the same vertical height.

Paradoxical as it may at first appear, then, the bottom in this case will suffer a pressure greater than that of the liquid contents of the vessel.

"*Experimental proof of the law—Pressure as vertical depth.*"

302. By putting different heights of liquid into an upright tube, of which the bottom is closed by a flap having a spring or lever to support it, we find that for a double, triple, &c. height of column the lever must be loaded with double, triple, &c. weights, indicating double, triple, &c. pressing force.

Suppose vessels differing from each other in form and capacity, as sketched at *a*, *b*, and *c* (fig. 78), but all having flat bottoms, of exactly the same area. By having the bottoms movable, and held to their places by weights or springs capable of indicating the pressure borne, we find that if fluid be poured into all to the same level or perpendicular height, as represented here by the dotted lines, although the quantity be very different in each, the pressure on the bottom will be the same in all. Or by letting the three vessels all communicate with the same vessel of water below them, we infer the equality of pressures from the fact that the water is supported in all at the same level.

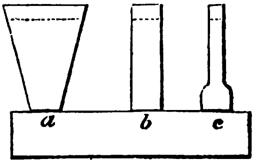

Fig. 78.

303. The following are farther illustrations of the pressure increasing with the depth:—

A tube two feet long and a square inch in section, holds nearly a pound of water; hence the pressure of water at any depth, whether on the side of a vessel, or on its bottom, or on any body immersed, is only a little less than *one pound on the square inch for every two feet of depth*—a general truth well worth keeping in memory.

A bubble set at liberty far below the surface of water, is small at first, owing to the compression, and gradually enlarges as it rises.

The effects of liquid pressure at great depths are most strikingly exhibited at sea.

If a strong square glass bottle, empty, and firmly corked, be sunk in water, its sides are generally crushed inwards before it reaches a depth of ten fathoms.

A water-tight wooden chamber, if similarly let down with a man in it, would quickly allow him to be drowned by the water bursting in upon him ; as once actually happened to an ignorant projector.

When a ship founders in shallow water, the wreck on breaking to pieces generally comes to the surface, or floats, and is cast upon the beach ; but when the ship sinks in deep water, the great pressure forces water into the pores of the wood, and renders it so heavy that no part can ever rise again to reveal her fate. Thus it is that a whaling-boat drawn down to a great depth by a whale, never reappears on the surface.

A diver in deep water suffers much from the compression of his chest, as the elastic air within yields under the strong pressure. This limits the depth to which ordinary divers can safely go.

It is not known whether there is a limit to the pressure which fishes can bear with impunity, but they abound chiefly in the shallower waters on coasts, or on banks in the midst of the ocean, such as the banks of Newfoundland, the Dogger-bank, or the bank of Lagullas, off the Cape of Good Hope. At the abyssal ocean depths which are now being explored, the same animal life could not exist unprotected from the enormous liquid pressure as exists in the superficial layer. Hence the tiny creatures brought up in deep-sea soundings, from depths of 500 to 700 fathoms, are enclosed in calcareous shells, whose thickness increases with the depth at which their home may have been situated.

One way of proving the compressibility of water under enormous pressure, is to sink a vessel, prepared for the purpose, in the deep sea. The vessel has a small round opening, into which, instead of a cork, a sliding rod has been closely fitted. Thus, when it is sunk, the pressure will push the rod inwards, in a degree proportioned to the yielding of the water within ; and a stiff-sliding ring on the rod, or other contrivance, may be used to indicate how far the rod had been driven inwards, or the degree of compression at the greatest depth. In this way it has been found that water compressed by 1000 fathoms of water over it, or a force of 3,000 lbs. to the square inch, loses about one-hundredth of its bulk (Art. 294).

304. The following are proofs of the pressure produced by gravity in a free liquid operating equally in all directions.

A bottle-cork at the bottom of the sea would not be flattened as if it were pressed unequally, or only above and below, but would be reduced in all its dimensions, so as to look like a phial-cork.

By means of a valve or flap, so contrived as to tell the force required to keep it shut, we find that water tends to escape just as powerfully through an opening in the side of a vessel as through an opening in the bottom, with the same height of water over each. Equal openings in the side of a vessel must be closed with forces exactly proportioned to the heights of liquid above them.

In an open square-sided vessel full of water, *the whole pressure* on any upright side is just half of that on an equal extent of horizontal bottom. For, the centre of the side being just half as deep as the bottom, the pressure there is only half that at any part of the bottom; and on points above the level of the centre, is just as much less than half, as, at corresponding distances below, it is more than half. So it amounts to an exact half on the whole.

Considering that the pressure on every point below the central level is greater than on every point above it, we see why, in order to support a sluice or flood-gate by a single stay on the outside, the point at which the support has to be applied is below the central level. Calculation and experiment discover that this point, called the *centre of pressure*, is at one-third from the bottom. The knowledge of such facts furnishes rules for the construction of large vessels to hold liquids, and of canal and other embankments.

The pressure on the upright side of a deep narrow vessel is just as great as on the same extent of side of a wide vessel, having the same depth of fluid : because it depends merely on the extent of surface acted upon, and the depth of liquid.

Hence a flood-gate which shuts out the ocean, as in docks opening to the sea, bears no more pressure than if it formed the side of a vessel so narrow that a few hogsheads of water would fill it.

A deep crevice in a rock, if filled by rain, may cause the rock to split or be torn asunder.

Extensive walls or faces of masonry, intended to confine banks of sand or earth, if left without low openings for water to escape from behind them, may be burst after rain, unless they have the strength of flood-gates of the same size. Ignorance of this danger has led to some extraordinary catastrophes.

Other examples of liquid pressure being exerted in all directions, and proportioned always to the depth, are: the swelling and bursting of leaden pipes when filled from a very elevated source; the tearing up of the coverings of subterranean drains or watercourses, when, during a flood, any accident chokes them near their lower openings; the violence with which water escapes by an opening near the bottom of any deep vessel, or enters by an opening or leak near the keel of a deep-floating ship; the great strength required in the lower hoops and securities of those enormous porter-vats which contain sometimes thousands of barrels of liquid.

305. Some persons have a difficulty in conceiving that within a liquid there is an *upward* as well as a downward and a lateral pressure. But if the particles below at every point of a liquid had not an upward tendency equal to the weight or downward pressure of the fluid over them, they could not support that column, but would move away, which they do not. Their tendency upwards is owing to the surrounding pressure from which they are trying to escape. If a glass tube, open at both ends, and having a sliding plug or piston in it near one end, be plunged into water with the plugged end down, the water presses the plug up; and, by having a spiral spring inside the tube for the plug to compress, we may show that the pressure is always proportioned to the depth. On removing the plug, a column of water is pushed into the tube from below, and supported there at the level of the liquid around, by this upward pressure.

" *Level surface of a liquid.*"

> **306.** That the surface of a liquid which is at rest must be level, follows from the perfect mobility of the particles among each other, and from their being equally attracted towards the centre of the earth.

The particles forming the surface may be regarded as the tops of so many columns of particles, supported by a uniform resistance or pressure below; for no particle below can be at rest unless urged equally in all directions, and therefore all the particles, at any one level, which, by equally urging one another, keep themselves at rest, must be bearing the weight of equal columns. Thus a higher column, however produced, must sink and a lower one must rise, until just balanced by those around; that is, until all become alike. Besides, just as a ball rolls down a slope or inclined plane, so all the particles of a fluid glide down among each other till each occupies the lowest possible situation.

This explains why the elevation and depression of a liquid surface, called a wave, continues to rise and fall, or to oscillate, for some time with gradually diminishing force. A column raised above the general level, as it cannot be supported, must sink; but in sinking, like a falling pendulum, it acquires momentum which carries it as far below the general level. Pressed up again, and acquiring new momentum in its rise, it has once more to fall, and so this alternation continues, until the lateral sliding of the particles, and the friction among them, gradually destroy the oscillation.

307. The surface of a liquid is always level when at rest—but only when at rest. If we pour some oil over water in a tumbler, the separating surface is perfectly flat: and we may pour some spirits over the oil, yet each will keep separate and sharply defined when the whole is once tranquil. On the other hand, the slightest breath disturbs the perfect smoothness of a lake, so that it no longer mirrors the distant landscape in harmony, but sends to the eye a confusion of images. So the hollow shape given, by stirring, to the surface of tea in a cup, subsides into the perfect level as the motion ceases.

The law of fluid level may be also stated as follows:—

308. "*If various tubes and vessels communicate with one another, water admitted into any one of them will rise to the same level in all.*"

Fig. 79 represents a variety of tubes and vessels, opening into the box, G. Water poured into any one would fill the box, and would then rise to the same level in all, so that if it stand at *a* in the first, and at *f* in the last vessel, all the surfaces between will form with *a f* a horizontal line. The reason of this has been already given in Art. 301, where it was stated that the pressure depends not on the shape of the vessel, but only on the vertical height of liquid.

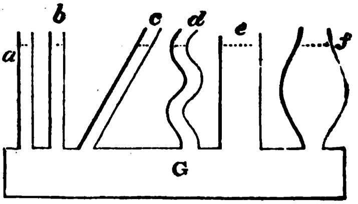

Fig. 79.

If a tube twenty miles long, and rising and descending among the inequalities of a country, were filled with water, and could have its ends brought together for comparison, it would exhibit two liquid surfaces having precisely the same level; and on either end being raised, the fluid would sink in it, and cause an overflow from the other.

309. Many important phenomena find an explanation in this apparently simple statement.

An easy mode of determining the horizontal or level line at any spot is to have an open tube, bent up at its ends, *a* and *b* (fig. 80), and nearly filled with liquid. By then looking along the two liquid surfaces, or through floating *sights* resting on them, an observer can tell whether one or more objects are in the same horizontal line with *a b*, or not.

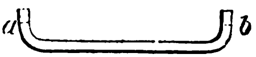

Fig. 80.

If there were two lakes at different levels on adjoining hills, a pipe connecting them through the valley would soon bring them to the same level; and if the bottom of one were above the bank of the other, it would empty the upper lake into the lower.

It was at one time supposed that the Dead Sea in Palestine had a subterranean communication with the Mediterranean, from which it is about fifty miles distant; but apart from the fact that the water of the Dead Sea contains a much greater proportion of salt than the water of the inland sea, the difference of level is altogether inconsistent with this supposition. According to the measurement made by Lieutenant Symonds in 1841, the surface of the Dead Sea is 1312 feet below the surface of the Mediterranean. Mr. Moore found no bottom in it at the great depth of 2220 feet. Hence it follows that the basin of the Dead Sea represents an enormous chasm in the earth upwards of 3500 feet in depth, below the level of the Mediterranean on the Syrian coast.

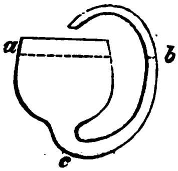

Fig. 81.

A projector once thought to solve the problem of perpetual motion by using a vessel shaped as in fig. 81. He reasoned thus: A pound of water in the goblet, *a*, must more than counterbalance an ounce which the tube, *b*, will contain, and must therefore be constantly pushing the ounce forward into *a* again, and keeping up a circulation, which will cease only when the water dries up—a result easily preventable. He forgot that a common teapot is nearly such a vessel, and yet does not overflow.

A glass tube, running down the outside of a cask or cistern, and connected with it at the bottom, shows at once the level of the mass of liquid within. By a similar contrivance the engineer sees the level of water in the boiler of his engine, and thus knows how to regulate its supply.

So a chemist is thus able to determine the precise quantity of gas contained in a gas-holder when the gas has been collected over water.

In like manner a pipe brought from a river into a neighbouring cellar or pit, will indicate the height of the water in the river.

A gigantic illustration of the principle that "water always seeks its level," is seen in the ramifying system of pipes by which water is now distributed through all large towns. Brought or pumped up to an elevated site near the town, it rises by the mere effect of its perfect mobility and of gravity to every cistern not above the level of the reservoir, however tortuous its course may be.

We are not to suppose that it was ignorance of this law ot liquids, that led the ancients to construct those enormous aqueducts, some of which are scarcely inferior in magnitude to the great wall of China or the Egyptian pyramids. The want of a suitable material such as iron imposed on them the necessity of all this enormous labour; just as the invention of printing was delayed not by the want of the idea so much as of the *material means* of making impressions readily.

On the possession and knowledge of the qualities of this tough and workable substance which we call iron depends the health and wealth of imperial London. Like the arterial and venous circulation in the animal body, is the supply of pure water and the drainage of impurities through all the districts of our huge metropolis; although we are now so habituated to the fact, that we do not think on how little turns our superiority to our less favoured ancestors.

310. "*Levelling.*"

In the cutting of canals, in the making of railways, and in many other engineering operations, it is of essential importance to have a delicate means of determining the level or horizontal direction at any place. For this purpose engineers and builders use the *spirit* *level* (fig. 82); it is a tube of glass like *a c*, containing spirit of wine and a small bubble of air, *b*. The tube is slightly convex or curved on the upper side, so that, when it is laid on a horizontal surface, the bubble, rising to the highest part, stands at the centre of the tube, which the maker of the instrument has marked with a slight scratch. If the surface on which it rests deviates ever so little from the horizontal, the centre of the tube is no longer its highest part, and the bubble instantly moves towards the higher end. Spirit of wine is used in preference to pure water, because it is more limpid, and has less adhesion to the glass than water, and thus furnishes greater delicacy of movement. Such a tube properly fixed in a frame, with a telescope attached to it, becomes the engineer's guide in his most important operations.

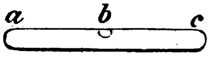

Fig. 82.

A perfectly level surface on the earth really means one in which every point is equidistant from the centre of the earth. It is therefore truly a spherical surface like that of the earth; but so large is the sphere, that if a slice of it two miles in diameter were cut off and laid down on a *true plane*, the centre of the slice would be only four inches higher than the edges. Any small portion of it may therefore be practically regarded as a perfect plane.

Thus a hoop surrounding the earth would bend away from a perfectly straight horizontal line four inches in the first mile. In cutting a level canal, therefore, which may be considered as part of such a hoop, there must be everywhere a falling from the straight line called *a tangent*, in the proportion now described. All rivers also must have this curvature, and a little more, to produce the running motion.

A very slight declivity from the level suffices to give the running motion to water. Three inches per mile, in a smooth straight channel, gives a velocity of about three miles per hour. The Ganges, which gathers the waters of the lofty Himalayas, is, at eighteen hundred miles from its mouth, only eight hundred feet above the level of the sea—that is, about twice the height of St. Paul's; and to fall gradually these eight hundred feet, in its long course, the water takes nearly a month. The gigantic Rio de la Plata has so gentle a descent to the ocean, that in Paraguay, fifteen hundred miles from its mouth, large ships arrive which have sailed against the current all the way, by the force of the wind alone. On the gently inclined plane of the stream, they have been gradually lifted by the soft wind, even against the current, to an elevation greater than that of our loftiest spires.

311. "*Canals.*"

When the difference of level between two places is very considerable, and the ease and convenience of water-intercourse are desired, recourse is had to the construction of canals, divided into portions at different levels like the steps of a stair. Boats are raised or lowered from one level to another by the contrivance called a *lock*, which is merely a portion of the canal, of sufficient length for the boat to lie in, provided with high walls, and with flood-gates at both ends. When the gates below are shut, and water is admitted from above, the lock becomes part of the high level, ready as such to receive a boat, or to deliver one : and when the upper flood-gates are shut, and the water is gradually allowed to escape from below, the lock becomes part of the low level, and a boat may enter it or leave it by its lower gates. The rising at these gates varies from six to twelve feet.

The cutting of canals is one of the great items in the mass of modern improvement, which both mark and hasten the progress of civilization. To show their importance as facilitating intercourse, we need only say here, that a horse which can draw but one ton on our best roads, can draw thirty with the same speed in a canal-boat.

One of the grandest works of this description is the Isthmus of Suez maritime canal, which was commenced in April, 1864, and completed in November, 1869, chiefly under the direction of a French engineer, M. de Lesseps. It is not quite a hundred miles in length, extending from the new harbour of Port Said on the Pelusian coast of the Mediterranean to the Port of Suez at the head of the Red Sea. Its construction was attended with enormous engineering difficulties, and is said to have cost about sixteen millions sterling. There are no locks, but in some parts it traverses sandy deposits and in others high rocky ground. Its depth throughout is 26 feet, and its width 246 feet at the base, and 328 feet at the top of the banks. By means of this canal large vessels can now pass directly from sea to sea. The project of another great ship canal across the Isthmus of Panama has been lately revived ; but the difficulties in joining the Atlantic with the Pacific Ocean are likely to be greater than those which were encountered in connecting the Mediterranean with the Red Sea.

312. This earth, with the circulation of water upon its surface, has been likened to the animal body, with its circulation of renovating blood. In the animal machine the moving agent is the heart, which acts as a forcing pump, sending the blood charged with fresh nourishment along the arterial channels to every part of the system, and thence back again by the veins to the heart to be re-charged. In the machine of nature, the great motive agent is the sun, whose heat raises aloft from the extended surface of the oceans and lakes, perfectly pure water to be diffused over the earth by the winds—these also, as we shall see, are effects of the solar heat—and to be deposited again in the form of rain, dew, or snow, as a life-giving drink to the animal and vegetable creations, and ultimately to return to the bosom of the ocean from which at first it sprung.

313. In order to understand the effect of this water, as it seeks the level of the ocean, in shaping the present features of our globe, we shall consider the following miniature case:—

A mill-pond, suddenly emptied by a sluice at its lowest part, would exhibit a variety of pits and pools left among the inequalities of the bottom. The subsequent fall of rain would cause each pool to overflow, and send out a streamlet either into another lower pool, or into a channel leading directly to the sluice. Thus there would be a constant wearing down of the side of the pool over which the water is running, and a lowering of the surface of water in the pool, while, at the same time, the bottom would be rising, owing to the deposit of matter washed down by the rain from the elevations around. These two operations continuing, the pool would at last disappear, and so the whole bottom of the emptied mill-pond would at last become only a wrinkled surface of dry land, with a beautiful ramification of water channels, all sloping with inimitable precision towards the general mouth or estuary. In every case, a watercourse soon becomes singularly uniform, both as to dimension and descent, because any hollows are gradually filled up by the sand and mud carried along in the stream, and deposited where the current is slack ; while any elevations are gradually worn down by the action of the more rapid current which accompanies shallowness.

This is but a picture of what has been going on over the face of this earth ever since the local convulsions or more tranquil upheavals and depressions which led to the present unequal distribution of land and water. In many places the effect of the gradual draining is already complete; in others it is only in progress. Geologists have proved that much of the present dry land had, in remote ages, been sea-bottom, and that great part of it is but the hardened deposit from moving water of mud and sand, having embedded within it the innumerable shells, bones, and other remains now found, of the living beings which inhabited the earth during the change. It is thence concluded that our present continents and islands must have been upheaved from the bottom of an ocean, or an ocean must have subsided away from them ; and that in either case the land must have emerged as chequered and unsightly as the bottom of our emptied mill-pond. But the gradual operation of "*water seeking its level*" has converted these primary inequalities and corrugations into the lovely plains and regular alternating water-courses which we now enjoy.

Nor is this a mere fanciful picture. Slight observation of the face of our globe shows that the extensive plains along the course of many rivers are evidently formed of the clay or sand which the stream has borne down, and may still be carrying down from the higher lands; while the remains found embedded in the soil are the shells and bones of such animals as have lived in the river or on its banks. These plains had been in remote time deep hollows or lakes surrounded by barriers of elevated land, through which the chief passages were those by which the river now enters and leaves them, which passages had evidently been gradually cut deep by the action of running water. The great delta of the Nile is now proved to be made up of the surface soil of the lofty mountains of Abyssinia, brought down annually by that river and deposited in Lower Egypt during the floods.

314. In former ages the Rhine, for instance, has been the drain of a chain of such basins or lakes, which have in this way been gradually filled up. This operation is seen to be still going on in all the lakes of the earth. It is ascertained that since the time of Julius Cæsar an extent of about three miles at the upper part of the Lake of Geneva has been converted into dry land by the wearings of the Alpine mountains, brought down by the winter torrents. Several villages that were close upon the lake some centuries ago, have now fields and gardens spreading between them and the shore; and if the town of Geneva last long enough, its inhabitants will have to speak of the river threading the neighbouring valley, instead of the picturesque lake which now fills it. In illustration of this subject, it is interesting to observe the contrast between the proverbially pure blue water of the Rhone as it issues from the Lake of Geneva, and the turbid streams which enter it from above and around. These having deposited all their load of mud and sand in the still bosom of the lake, become the clear water of the river below. The streams which, below the lake, join the Rhone directly from the Alps, are long distinguishable by their muddy waters.

When, in the course of a river, there is no lake to intercept the solid matters which it carries down, these ultimately reach the sea, and form the deltas or regions of flat country seen at the mouths of rivers. There is an extensive formation of this kind at the mouth of the Rhone. The greater part of Holland is a similar deposit from the Rhine. The whole of Lower Egypt, and much of the flat fertile land higher up, has thus been formed by the Nile; much of Bengal has been formed by the Ganges, and so forth.

Where the soil or bed of a country through which a water-track passes is not of a soft consistence, so as to allow readily the wearing down of higher parts, and the filling up of hollows by deposited sand, lakes, rapids, and great irregularities of current remain. We have, for instance, the line of lakes in North America, the rapids of the St. Lawrence, and the stupendous Niagara, where at one leap the river falls one hundred and sixty feet. A softer barrier than the rock over which the river pours would soon be cut through, and the line of lakes might be emptied.

The consideration of the fact that water is constantly wearing where it flows, and carrying the abraded portions down to lower levels, and ultimately to the ocean bed, forces upon us the idea that this earth can have but a limited existence in its present state. Every shower sends portions of mountain and plain into the depths of the ocean, and thus causes a corresponding encroachment on the shores by the rising water. It is ascertained that the River Ganges alone carries down every year, and deposits in the Bay of Bengal, more solid matter than would cover the whole surface of England to a considerable thickness. With revolving ages, therefore, unless the causes which have operated in past time to upheave portions of the earth's crust from beneath the sea continue to operate, the whole of the present dry land must disappear. Human art may for a time succeed, as in Holland and elsewhere, in shutting out the ocean from some low tracks by means of sea-dykes or embankments, but its power is utterly insignificant when set against the great forces of nature.

There is, perhaps, no fact that illustrates in a more striking manner the exact accordance of all nature's phenomena with the few general expressions called laws which describe them, than the steady maintenance of the mean height and level of the ocean as a liquid surface. The sea, although having in most parts a depth of thousands of feet, which fluctuates several feet twice in every day with the flood and ebb-tides, never rises or falls in any place, even one inch, but in obedience to fixed laws, which men can study. Were it not for this perfect exactness, in what a precarious state would the inhabitants exist on the sea-shores, and on the banks of low rivers! Few of the inhabitants of London, perhaps, reflect, when standing by the side of their noble river, and gazing on the rapid flood-tide pouring inland through the bridges, that, at the moment, the level of the wide ocean around the mouth of their river is several feet higher than that of the water near them.

The destruction that would follow a slight alteration in the level of the ocean, may be judged of by the effects of occasional floods, produced by rains and melting snow in the interior of countries, or by these combined with winds and high tides on the coasts. The accounts which have been published, under the title of *Inundations*, are truly appalling. In Holland, which is a low flat, formed chiefly by the mud and sand brought down by the Rhine and neighbouring rivers, much of the country is really below the level of the common spring-tides, and is protected from daily inundations only by artificial dykes or ramparts, intended to be strong enough to resist the ocean. Partial failures of these have been frequent; and, in the year 1580, a more extensive failure caused an inundation which drowned four hundred thousand people.

Where moderate inundation is regularly periodical, as in the Nile and many other rivers, the hurtful effects can be guarded against, and the occurrence may even be rendered highly useful in fertilizing the soil. Tracts of land in contact with rivers, where the surface lies between the levels of ebb and flood-tide, if surrounded with dykes, may be kept constantly covered with water, by sluices made to open only at high water, or may be kept constantly drained, by sluices which open only at low water. A vast extent of rice-fields, near the mouths of rivers in India and China are managed in this way, the admission or exclusion of water being regulated by the age of the rice plant. A great part also of the rich sugar plantations of Demerara, Essequibo, &c., on the coast of South America, are supplied with water under similar circumstances.

315. The subject of *fluid level* leads to the consideration of springs or wells, and of the operation of boring for water.

The rain which falls over the land, and which must ultimately return to the sea, may find its way to the river channels, either by running directly along the surface of soils which refuse it admittance, or by first sinking into porous earth, and then oozing out at lower situations in the form of springs. If a spring be as low as the bottom of the porous earth from which it issues, that is to say, as low as the surface of the impermeable clay or rock on which at some depth all such earth rests, it may drain the whole; but if not, the water will stand at a certain level among the earth as water stands among bullets in a tub. If a hole be then dug in such earth to below the level of the water lying there, it will soon be filled with water up to the level around, and will be called a well. In many places this water-level is very far below the surface of the ground; and in some places, by reason of the water having an easy drainage from the earth towards the sea, or of the superficial soil being altogether impervious to water, no well is to be found at all.

A remarkable illustration of this subject occurred some years ago in Kent, on the occasion of cutting between Rochester and Gravesend the canal then called the Thames and Medway Canal, now transformed into a railway. This canal consisted of but one cut or level, about seven miles long, two of which were in a tunnel through the hill. The level was that of high water in the connected rivers; the intention having been to let the canal be filled always from the rivers at high tide: but as the permanent level of the subterranean water in the surrounding land, and therefore of all the wells of the inhabitants was, as should have been anticipated, half-way between the sea levels of high and low tides, the salt water from the rivers was no sooner admitted to the canal, than it spread into the land on both sides, where the resisting internal water-level was lower, and spoiled all the wells. If the canal had been dug a few feet lower, the evil would not have occurred, and the company would have escaped paying the heavy damages which rendered their undertaking a very profitless speculation.

The case has occurred, and it illustrates the general principle of water seeking its level, where, on wells being sunk to a lower level than cess-pools in the immediate vicinity, the water has been soon contaminated with the noxious products of sewage. Typhoid fever and other fatal diseases have been traced to accidents of this kind.

Again, wells for the supply of water have been sunk near cemeteries and graveyards, which have thus been made receptacles of water percolating through the soil carrying with it the products of decomposition and the germs of disease. It is fortunate that science can now discover, and in some measure avert, these dangerous consequences. A scientific system of drainage, and a proper study of the subject of water-level, have to some extent removed the evils arising from this ignorance of a common principle in hydrostatics.

It is worthy of remark here, that high cultivation or the agricultural improvement of a country has a great effect on the quantity of spring water in it. While the face of a country is rough or uncultivated, the rain water remains long among its inequalities, slowly sinking into the earth to feed the springs, or slowly running away from the surface of bogs and marshes towards the rivers. Hence the rivers have a comparatively uniform and regular supply, even when rain has not fallen for a long time; but in a well-drained country, the rain, by the numerous artificial channels, finds its way to the brooks and rivers almost immediately, and produces often dangerous floods or inundations of the neighbouring low grounds.

The surface of our globe is formed chiefly of distinct layers of clay, chalk, sand, gravel, &c., originally deposited from water, but afterwards solidified, and in many places upheaved, by subterranean agencies, into great varieties of position. In particular situations these strata have taken concave shapes, becoming like cups or basins placed one within another. Now as water, poured in to occupy the space between two basins so placed, would rush through any hole made in the bottom or side of the inner basin, to the height of the water around it, so on boring for water through an interior water-tight stratum or basin of clay, the water often springs out and rises above the surface of the ground. Such a spring is called an "Artesian well," from having been common in the province of Artois in France. London stands in a hollow or basin of clay, placed over chalk which contains water, and on boring through the clay, the water issues, and rises often considerably above the surface of the ground; showing that there is a higher source or level in the chalk among the hills of Surrey, Middlesex, or Hertfordshire. Numerous artesian wells have also been bored in the neighbourhood of Paris, one of the most famous being that at Grenelle, where the water rises from a depth of nearly 1800 feet below the surface, and is further carried to a height of a hundred feet above it, furnishing a supply of beautifully clear water at the rate of 800,000 gallons a day

316. When fluids of different weights for the same bulk are made to balance each other in communicating vessels—as water, for instance, in one leg of the bent tube, *b d c* (fig. 83), and oil in the other—the surfaces will not settle at the same level; but the surface of the lighter fluid will be just as much higher than that of the other as it is lighter. Thus a column of oil must be of the length, *d o*, to balance a column of water, *d w*; and alcohol, because lighter than oil, to balance the same water, would have to stand higher still, as at *a*; while mercury, being thirteen times heavier than water, bulk for bulk, would stand only about *m*. The shape, size, or position of the vessels in which the opposing fluids might stand would have no influence on the relative heights of the surfaces (Art. 301). Were a larger vessel, such as is represented here by the dotted lines between the letters *e f m*, to be substituted for the leg, *c d*, of the tube, the various fluids to balance the water in *b d*, would have to stand just as high in it, as in the smaller tube.

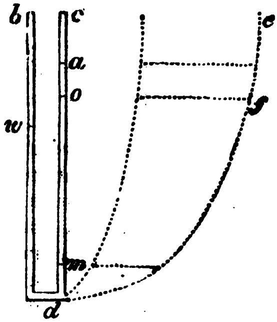

Fig. 83.

"*The principle of Archimedes.*"

317. "*A body immersed in a liquid or fluid displaces exactly its own bulk of it. This quantity having been just supported by the fluid around, the body is buoyed up with a force exactly equal to the weight of the displaced fluid, and must sink or float according as its own weight is greater or less than this.*"

That a body immersed in water displaces a quantity of water exactly equal to its own bulk, may be demonstrated by a very simple experiment: Immerse by a thread a cubic inch of bronze in a glass vessel containing water, and graduated to cubic inches and fractional parts. The water will rise, and it will appear as if another cubic inch of the liquid had been added to the contents of the vessel. A cubic inch of water is simply displaced by a cubic inch of bronze. What is true of a cubic inch, is true of any solid, however irregular its form. Thus the exact bulk of any mineral may be determined by immersing it in the graduated vessel. When all the air is removed from the surface of the solid, the bulk will be determined in cubic inches by the water displaced.

An inflated bladder, or india-rubber balloon, with exactly the bulk of a pound of water, requires a force of one pound (except the few grains which it weighs) to force it under water. The same bulk of gold is pressed upwards in water with exactly the same force; so that, if previously balanced at the end of a weighing beam, it appears on immersion to have lost one pound of its weight. A piece of wood, ivory, or any other substance, having exactly the same bulk is pressed up on immersion in the liquid by the same amount.

318. The reason of this is obvious, for the immersed body takes the place of water which weighed one pound and yet was supported, and whose pressure was necessary for the equilibrium of the rest. In a vessel of water, *a b* (fig. 84), a single column of particles, such as *c d*, is supported in its place by the surrounding pressure, which is exactly equal to the weight of the column; and what is true of a column of single particles, is true of any other portion, such as that represented by *f h g*. If such portion weighed exactly a pound, its under surface would be tending upwards with the pressure of a pound; and if, without changing its bulk or form, it were to become ice, it would still be exactly supported by the pressure below; and of course, if a similar column of wood, or stone, or metal, were there, the surrounding pressures would still be the same. Again, if only *h g*, or half the column, were solidified, it would still be buoyed upwards with the pressure of a pound at *g*; but its own weight of half a pound, and the weight of the half pound of water resting above it, would still produce an exact balance.

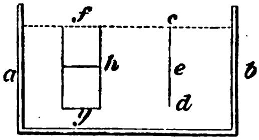

Fig. 84.

It is very important to have clear notions on this subject; and as different minds apprehend such matters with different degrees of facility, and in different ways, we shall state the same general truth in other words.

319. Let us consider a mass of fluid as consisting of a vast number of extremely minute columns of single particles standing side by side, where every particle supports those above it by the tendency upwards which it acquires through the pressure of the fluid below and around it. Then if we suppose the particles of a portion of the fluid mass, of any shape, to stick together, or to become ice without change of bulk or weight, that portion when solid would still be between the same forces as when fluid, and therefore would be equally supported, and would remain at rest. If gold, silver, glass, or wood, having the same bulk, were substituted for the supposed ice, such new substance would still be pressed upwards with the same force; so that a substance of exactly the same weight as the displaced ice or water would have no tendency either to rise or to fall more than the water itself had; but a substance heavier would sink, and one lighter would swim, and in either case with a force exactly proportioned to the difference between its weight and that of an equal bulk of water.

Few reading this statement would imagine that a truth apparently so simple could have so long remained unknown, and that the discovery of it should be accounted one of the most important ever made—but such is the case. The discoverer was Archimedes, the most famous of the ancient Greek geometers. He caught the idea one day while his limbs were resting on the liquid support of a bath; and as his far-seeing intellect at once descried important applications of the principle, he is said to have been so overjoyed with his discovery that he leapt from the water, and almost naked pursued his way homewards, calling out "῞Ευρηκα, ἕυρηκα,"—"I have found it, I have found it."

This principle discovered by the Greek philosopher has found many most important applications. It is of course the fundamental consideration in every case of floating; hence, in marine architecture or ship-building, careful attention must be given to the deductions from this principle, and many serious catastrophes have occurred from neglect of these, as when the splendid man-of-war the 'Captain' went down with almost every one on board.

As it gives the ready means of ascertaining the *specific gravities* of bodies—as gold, silver, copper, &c.—that is, their weights, bulk for bulk, compared with water; and in the case of mixtures—as of gold with silver, for instance—of determining the proportion present of each, it is essential to the chemist in distinguishing one substance from another, and in discovering the nature of mixtures or compounds; and often to the merchant in judging of the worth of his merchandize.

320. The following are further illustrations of the truth, that a body immersed in a liquid is buoyed up with force equal to the weight of liquid it displaces:—

A stone which on land requires two men to lift it, may be lifted and carried in water by one man; but he will find that he is unable to lift it *out* of the water. There are cases where the support of water is in this way equivalent to the assistance of an additional hand.

In operations under water—such as laying the foundations of piers and bridges, or searching sunken wrecks—which men are enabled to conduct with facility by means of the diving-bell and diving-helmet, the difference in the weight of objects in water compared with their well-known weight in air, appears to the workers below very striking. Their own limbs are lighter, and they must be heavily loaded with leaden weights to keep them down, and give them any power to move objects: otherwise on attempting to move a heavy box or stone, they would but push themselves farther away from it, or pull themselves nearer to it, in accordance with the principle of action and reaction already explained. On returning to the air they experience the surprising sensation of heavy or loaded limbs.

This feeling is also experienced by a person on first lifting his limbs out of water, if, as in taking a bath, he has been in it for some time. They seem to get suddenly heavier, and require increased energy to move them about.

This fact explains also why stones, gravel, sand, and mud are so easily moved by waves and currents. People express astonishment when they hear that a storm may displace huge blocks of stone weighing each many tons, as has happened in the construction of breakwaters; they do not reflect that the moving water has only to overcome about half the weight of the stone.

A man walking barefooted in deep water, may tread upon sharp flints or broken glass with impunity, because his weight is nearly supported by the water.

Further examples of loss of weight in water.

321. Most fishes are nearly of the specific gravity of water, and therefore, if lying in it without making exertion, they neither sink nor rise very quickly. In olden times there was a general belief that fishes had no weight in water; and it is related as a joke at the expense of philosophers, that Charles II. having once proposed to his men of science to explain this wonder, many profound conjectures were offered, but none of them thought of trying what really was the fact. It was beneath the dignity of science in those days to make an experiment. At last a simple man balanced a dish of water in the scale of a weighing beam, and putting a fish into the water, found that scale preponderating just as much as if the fish had been weighed dry in the scale-pan. This experiment may be readily performed by balancing a leech, and afterwards transferring the leech to a balanced beaker of water. The weight will be found to be the same whether the leech is in the scale-pan or in the balanced beaker, and whether the animal is moving in the water or adhering to the side of the glass.

In the sense now explained, water is said to have no weight in water. The least force will raise a bucket of water from the bottom of a well to the surface; but if the bucket be then lifted at all farther, its weight is felt, just in proportion to the part of it raised above the surface.

"*Floating.*"

322. "*A body lighter than its bulk of water will float in water, submerged to an extent proportioned to its specific gravity or relative weight compared with water.*"

The reason of this is clear. A block of wood, that it may remain floating out of the water, as represented in fig. 85, must have, in its whole volume, only the weight of the water which the immersed part of it displaces, because the upward pressure which supports its weight is just equal to this weight of water. If it be lighter than this, it will rise farther; if heavier, it will sink farther, until the exact balance be produced.

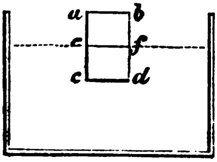

Fig. 85.

Hence any floating body which weighs a pound, displaces just a pound of water, whatever be the size of the body, and whether it be cork, or wood, or glass, or iron. This is experimentally shown by putting such bodies in succession to float in a vessel full of water. The water displaced by each will run over the sides of the vessel, and will always weigh just a pound.

Hence an empty basin, whether of glass, or porcelain, or metal, weighing a pound, will sink in water only as far as a wooden one of the same external dimensions and of the same weight; and the weight of the basin may be in the substance of which it is formed, or in anything else put into it as a load.

Hence an iron boat floats just as high out of the water as a wooden one of similar form and size, provided the iron be proportionally thinner than the wood, and the vessel not heavier on the whole. An empty metallic pot or kettle may be seen floating with a great part of it above the surface of the water. Prejudice for a long time deterred men from building iron boats or ships, though possessed of many advantages over wood.

Hence a ship carrying a thousand tons of cargo will just draw as much water, or float to the same depth, whether the cargo be of cotton or of lead; and the exact weight of any ship and cargo may be determined by finding how much water the floating ship displaces, which can be known by the depth to which she sinks in the water. In canal boats, which are generally of a simple form, this affords a ready means of ascertaining the quantity of their load.

323. A floating body sinks to the same depth whether the mass of liquid surrounding it be great or small. This is seen when a bowl is placed first in a pond, and then in a second bowl only so much larger that a few spoonfuls of water suffice to fill up the interval between them. One ounce of water may thus float a thing weighing several pounds—another form of the *hydrostatic paradox*. Even if a large ship were received into a dock, or case, so nearly fitting its form that there were only half an inch of interval between it and the walls of the dock, it would float as completely, when the few hogsheads of water required to fill this interval up to its usual water-mark were poured in, as if it were on the high sea. In canal locks, when the boats are made nearly to fit the space where they have to rise and fall, the cost of water to work the lock is much diminished.

"*Stability of floating; centre of buoyancy.*"

324. Similar reasoning to that which proves that the whole weight of a body acts as if it were lodged in the point called its centre of gravity, proves also that the whole buoyancy of a body, or rather the upward push of the fluid in which a body is immersed, acts as if lodged in the point which was the centre of gravity of the fluid displaced. This point consequently is called the *centre of buoyancy.*

A floating body, therefore, to be stable in its position, must either have its *centre of gravity* exactly below the *centre of buoyancy*,—in which case it resembles a pendulum hanging at rest, or it must have a very broad basis or bearing on the water, so that any inclination must cause the centre of gravity to ascend,—in which latter case it resembles a cradle or rocking-horse.

Hence arises, in the stowing of a ship's cargo, the necessity of putting the heavy merchandize low down, and often of putting iron ballast under all the ordinary merchandize. Hence also, comes the danger of having cargo or ballast which is liable to shift its place. A ship loaded entirely with loose stones is sometimes lost by a high wave making it incline for a moment so much that the load shifts to one side, which will then be kept down. For a similar reason, a cargo of salt, sugar, or saltpetre has a peculiar danger attached to it, for if the ship leak, or admit water, part of the cargo may be dissolved and be then pumped out with the bilge water, leaving the ship with altered trim.

Bladders used by beginners in swimming are dangerous, unless secured so as not to shift towards the lower part of the body.

"*Swimming.*"

325. *The human body, in an ordinary healthy state with the chest full of air, is lighter than water, and will float with nearly half the head above water; and in order to breathe, it is only necessary to keep the body at rest and the face uppermost.*

When the chest is empty, as in the act of expiration, its tendency is to sink. The specific gravity of the body depends on the specific gravities of its constituent solids. About 72 per cent. of the weight of the human body consists entirely of water; its specific gravity, therefore, depends on the remaining 28 per cent. of dry solids. The fat is the lightest part of the body, its specific gravity being 0·92, while bone is the heaviest. This has a specific gravity of 2·01. Hence, the floating and sinking of the human body will depend greatly on the relative proportion of these two constituents; the other parts of the body, such as muscle and other soft structures, having nearly the specific gravity of water.

If the facts connected with the buoyancy of the body were generally and practically understood, it would lead to the saving of more lives, in cases of shipwreck and other accidents, than all the life-preservers yet contrived.

The reasons that in water-accidents so many people are drowned who might easily be saved are chiefly the following :—

1st. They believe that the body is heavier than water, and therefore, that unless continued exertion be made, they must sink. Hence, instead of lying quietly and a little on the back, with the face only out of the water, they generally assume the position of a swimmer, in which the face is downwards, and the whole head has to be kept out of the water to allow of breathing. To do this requires practice; and if a person cannot swim, the first attempt at floating in this position will prove a disastrous failure.

2nd. The body raised for a moment by any exertion above the floating level, sinks as far below that when the exertion ceases; and the plunge terrifies the unpractised and renders them easier victims to their fate.

3rd. They make a wasteful exertion of strength to prevent water entering the ears, not thinking that it can fill only the outer ear, as far as the drum, and that this is of no consequence.

4th. They generally attempt in their struggle to keep their hands free above the surface, forgetting that any part of the body held out of the water, in addition to the face which must be out, requires an additional effort to support it. The tendency of the body to sink diminishes just in proportion to the quantity immersed; because all those parts which are out of water, not being supported by the water, become so much additional absolute weight to the portion immersed. This is indeed one of the most frequent causes of death by drowning.

5th. If the accident occurs at sea, they cannot, like the practised swimmer, choose the proper interval for breathing, which is when the crest of a wave has passed over and the head is for an instant above water.

6th. The chest should be kept as full of air as possible, which, without other effort, will cause nearly the whole head to remain above water. If the chest be once emptied, while the face is under water and the person cannot inhale again, the body remains specifically heavier than water, and will sink.

So little is required to keep a swimmer's head above water, that an oar will suffice as a support to several people, provided no one attempts to keep more than his head out of the water; but one or two, wishing to have as much of the security as possible, may submerge all the others.

The most common contrivances, called *life-preservers*, for preventing drowning, are strings of corks put under the chest or neck, or air-tight bags applied round the upper part of the body, and filled when required, by those who wear them blowing into them through valved pipes attached.

326. The most recent and complete of these inventions is the life-saving dress of Captain Boyton. It not only sustains the body beyond possibility of sinking, but it is at the same time so adjusted as to enable the wearer to make his way through the water and perform a variety of movements. The dress is made of vulcanized rubber, and is rendered buoyant by means of five air-chambers, which can be inflated or emptied through small tubes fitted with stop-valves. An upper chamber forms a complete air pillow for the head, and has the effect of always keeping the face uppermost and raised out of the water. A second chamber covers the entire breast, a third the back, and two others the legs. The whole of these are so adjusted to the body by a belt, as to be quite water-tight. The only part of the dress from which there is a possibility of getting wet is the face, but this is remedied by fully inflating the air-pillow at the back of the head. This draws the only aperture tightly round the chin, cheeks, and forehead. The feeling is said to be that of reclining at full length on an air mattress. It is not a swimming, but a floating-dress. It would require a weight of 300 pounds to submerge the body. Protected by this dress, the Captain on one occasion threw himself overboard in a rough sea off the rocky coast of Ireland, and after passing seven hours in the water he landed safely on the shore. A more surprising feat, however, was an attempt to cross the British Channel at night. On this occasion the Captain, properly invested in his life-saving costume, passed nearly fifteen hours in the sea-water, during which period it is calculated that he paddled himself or was drifted by the tide, a distance of forty or fifty miles. In May, 1875, he succeeded in crossing the Channel from the coast of France, and landed at Dover after twenty-two hours' immersion in the sea.

327. On the great rivers of China, where thousands of people find it more convenient to dwell in covered boats than in houses upon the shore, the younger children have a hollow ball of some light material constantly attached to their necks, so that in their frequent falls overboard they are not in danger.

Life-boats have a large quantity of cork mixed in their structure, or of air-tight vessels of thin copper or tin plate; so that, even when the boats are filled with water, a considerable part floats above the general surface.

Swimming is much easier to quadrupeds than to man, because the natural motion of their legs is that which best supports them in swimming. Man is at first the most helpless of creatures in water, though by his superior intelligence he can become so expert in this element as to be able to compete with its most active inhabitants. A horse while swimming can carry his rider with half the body out of the water. Dogs commonly swim well on the first trial. Swans, geese, and water-fowl in general, owing to the thickness of their feather-coating, kept dry by the oil spread upon them, as well as the great volume of their lungs, and the hollowness of their bones, are so light for their bulk that they float like stately ships, oaring themselves about by their webbed feet.

Fishes can increase or diminish the amount of water they displace, by expanding or contracting a little air-bag or bladder contained in their body, and in this way can rise to the surface of the water, or sink, at will. It is because this bag is situated towards the under side of their body, that a dead fish floats with that side uppermost.

Animal substances, when undergoing putrefaction, generate or give out a gaseous matter. Hence the bodies of drowned persons remaining in the water, generally acquire buoyancy after a few days, and rise to the surface, but they sink again when the still increasing quantity of gas bursts the skin and escapes.

328. *The buoyancy of a liquid increases with its weight or specific gravity.*

A ship draws less water, or swims lighter, by about a thirty-fifth part, in the heavy salt water of the sea than in the fresh water of a river; and for the same reason, a man swimming supports himself more easily in the sea than in a river.

Some men can swim easily in salt water who do so only with difficulty in fresh, and who would be altogether unable to support themselves if they suddenly fell into a vat of spirits, or wine, or oil.

Some kinds of wood that float in sea-water will sink in river-water, or which float in water will sink in oil.

A man would float on mercury as the lightest cork floats on water. One might even walk or hobble along the surface of mercury, sinking little more than ankle deep; but it would be very difficult to keep one's balance. Iron and all common metals float on mercury. Gold and platinum sink in it.

Had sea-water been a little heavier than it is, men after shipwreck would have had to think of famine and cold as much as of drowning. The water of the Dead Sea, in Palestine, has a specific gravity of 1·160. A man readily floats upon it. All parts of the dead body float upon it excepting bone.

329. One liquid floats upon or is buoyed up by another heavier than itself, because a pint of the lighter liquid displacing a pint of the heavier suffers an upward pressure greater than its own weight.

Thus oil floats on water, but sinks in alcohol or ether. Cream, consisting chiefly of oil or butter, rises to the surface of milk. Mercury, water, oil, and air all shaken together in a vessel, will, when left at rest, arrange themselves in the order of their weights or densities. Any liquids will do the same, if there is no adhesive attraction between them to make them form a compound liquid; and even in this case, by carefully pouring the lighter on the heavier, as wine upon water, the lighter will float for a considerable time without mixing. The following liquids may be thus placed upon each other, in the order of their respective densities:—Mercury, chloroform, water, olive oil, alcohol, and naphtha. On the surface of the last we may place the lightest metal known—lithium, which floats as readily on naphtha as iron or brass does upon mercury.

Wine that is rich in alcohol, if carefully poured on water, will float upon it. In a vessel shaped like a common hour-glass, as in fig. 86, only with a larger opening at *c*, between the two chambers, if wine be put into the under chamber, and water into the upper, the two liquids will gradually, to a considerable extent, change places. The liquids are less mixed, and change places sooner, when there is a tube, *b*, to carry the water down to the bottom without touching the wine, and a tube, *a*, to carry the wine directly to the top, without touching the water.

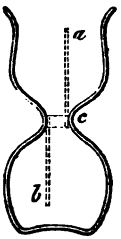

Fig. 86.

330. When, in a mass of water, part of it is heated more than the rest, that part, by its expansion, becomes specifically lighter than the rest, and takes its place on the surface. Hence, when heat is applied to the bottom of a vessel containing water, as to a boiler placed on a fire, a circulation is established, which goes on from the first moment until the communication of heat ceases: water is always rising from the hotter parts of the vessel, and descending from the upper and colder parts.

So when a tall glass containing hot water is dipped into cold water, a downward current begins within the tall glass near the sides all round, and an upward current in the middle. The motion is readily shown by putting small bits of amber or thin paper into the water, for these being nearly of the specific gravity of water, rise and descend with it. On account of these currents, heat applied to the bottom of a vessel of liquid is soon equally diffused through the whole; but if it is applied at the top the heated and lighter fluid cannot descend, and the heat passes but very slowly down through the liquid.

331. The currents in a fluid, produced by local differences of temperature, are important parts of various processes which the author suggested in the first edition of this work by the following paragraph :—

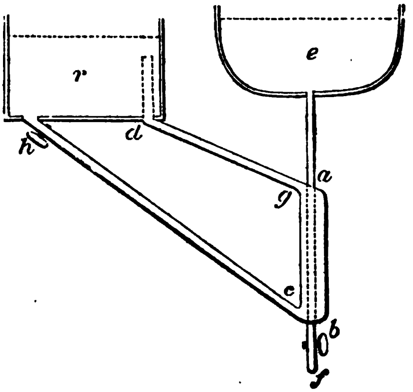

Fig. 87.

"Heat may be transferred from one liquid to another, without mixing them, by making the hot liquid descend in a very thin metallic tube, through the cold liquid rising around it in a larger tube. Boiling water from the vessel *e*, for instance, may descend slowly by the small tube *e a b f*, which is surrounded from *a* to *b* by cold water ascending through the tube *c g*. Then, as the temperature of two liquids brought so nearly into contact with each other as in these tubes will not, after a very short time, differ in any one place more than a few degrees, it follows that the water lately cold will, on leaving the part of the tube *g*, which is in contact with the boiling water descending directly from *e*, be nearly boiling, while the water lately hot will, on leaving the tube *b*, which is in contact with cold water just arrived from *h*, be itself nearly cold; and thus equal quantities of hot and cold water will not have become a double quantity of a medium temperature, but will have made nearly a total exchange of temperatures. The flow of the hot water is to be regulated by a cock *b*, and that of the cold water by a cock *h*. The water in the part of the tube *c g d* rises, because it is hotter and therefore lighter specifically than that in the part *h c*. The author believes that an apparatus made on this principle, with an arrangement of many thin flat tubes instead of a single large tube, for the descending fluid, and a spacious case, *c g*, to contain these and the rising fluid, would be an excellent refrigerator in a distilling apparatus, and for cooling the wort of brewers; or would serve as a means of diminishing the expense of warm baths, by transferring the heat from the water lately used to pure water. In distilling, the *wash* or *low wines* about to enter the still might be used as the cold condensing fluid to surround the worm or vapour tubes, and thus, without expense, would be heated in its progress to the still. Half the original expense of a great porter brewery is in the construction of the numerous water-tight floors on which the hot wort is thinly spread to cool."

Various practical applications of the principle explained in the preceding paragraph, which have been usefully made since the first publication of this work, are described in the chapter on Heat.

332. As a general rule, substances contract and become denser as they cool. Water, however, is a curious exception to this rule, for it contracts only down to the temperature of 40° Fahrenheit, below which, towards 32°, the freezing-point, it goes on dilating again, and in the form of ice is about one-fifteenth more bulky than water. Ice therefore floats on the surface of water, and being a very slow conductor of heat, defends the water underneath from the cold air, and preserves it liquid, and a fit dwelling for the finny tribes until the return of the mild season; just as very hot water in summer remains uppermost, preserving underneath an agreeable coolness. Thus nature has secured a winter garb or protection for the inhabitants of lakes and rivers, as effectual as it has for terrestrial animals, by the periodical thickening of their wool or fur. Had ice been denser than water, it must have fallen to the bottom, and have left the surface without protection; a deep lake, even in mild European winters, might have been frozen into a solid lifeless mass, which summer suns would no more have melted than they now do the glaciers of Switzerland.

"*Application of Archimedes' principle to finding* SPECIFIC GRAVITIES."

> **333.** The specific gravity of a body (that is, its gravity or weight compared with that of an equal bulk of water), may be found by comparing its weight with the amount by which it is buoyed up when immersed in water, since this buoyancy is the weight of its bulk of water.

Different methods of finding the amount of this buoyancy must be employed according as the substance whose specific gravity we wish to ascertain is in the form of a solid, of a powder, or of a liquid.

334. *Specific gravity of solids*

Suppose that we require to find the specific gravity of a solid body ***heavier than water***, such as a mass of gold. Fig. 88 represents the method employed in such a case. The mass of gold, *c*, is suspended by a thread or hair from the bottom of one scale *b* of a weighing beam, and is balanced by weights put into the other scale *a*. If then a vessel of water be lifted up under the solid, so that the water shall surround it, the body is buoyed up by the water with force equal to the weight of the water displaced. Weights therefore are required in the scale *b* to overcome the buoyancy or restore the balance, and these show the weight of the water displaced, or of water equal in bulk to the body. Thus the weights in the two opposite scales show the comparative weights of the body and of its bulk of water.

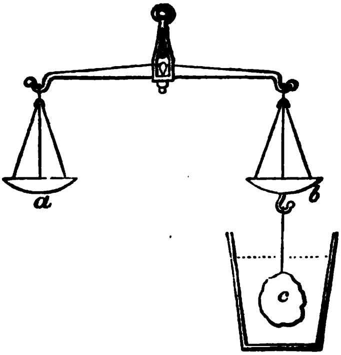

Fig. 88.

We should find in the case of gold, that the weight in the scale *b* would be about $\frac{1}{19}$th part of that in *a*; that is to say, gold loses $\frac{1}{19}$th of its weight when immersed in water, and is therefore 19 times as heavy as water, or has a specific gravity of 19.

The following is another but not very accurate method of obtaining a similar result. Take a vessel quite full of water, and lower into it by a thread any convenient weight of the solid whose density is required. Collect and weigh carefully the water which overflows. The specific gravity is then represented by the relative weights of the solid and of liquid so displaced.

The two facts on which the rules for determining the specific gravity of *solids* depend (Arts. 317, 318), admit of easy demonstration. 1. A body immersed in water displaces as much water as is equal to its bulk or volume. Thus a cubic inch of brass immersed in a glass vessel of water graduated in cubic inches, will cause the water to rise equally one cubic inch, just as if another cubic inch of water had been poured into the jar. But, in this case, a simple measurement of the solid cube would suffice to show its true volume. 2. The apparent loss of weight by immersion of the solid is exactly equal to the weight of the volume of water which it displaces. This may be proved by the following experiment :—

A cubic inch of brass, D, weighs in air, or is exactly counterpoised by 2014 grains. Assuming that that weight has been accurately determined, we suspend by a silk thread beneath a short scale-pan B (fig. 89), a hollow brass cube C, the cavity of which is exactly filled by the solid brass cube, D, which is itself suspended by a silk thread from the hollow cube C. We place in the scale-pan, A, the weights required to counterpoise B, C, D, in air. We then bring the glass vessel E, nearly filled with distilled water, below the short scale-pan B, so as to immerse the brass cube D in the water. The scale-pan B will rise immediately, as if there had been a loss of weight. This, as it has already been explained, is owing to the solid cube D being buoyed up by the pressure of the water around it. We ascertain the amount of this loss of weight by putting weights into the scale-pan B, and it will be found to be 252 grains and a fraction which need not be here considered. We now remove the weight from the scale-pan, and fill the hollow cube C with distilled

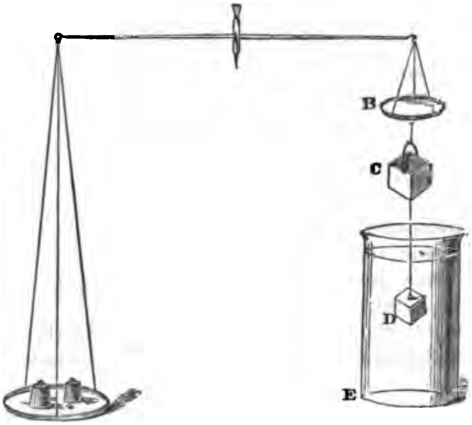

Fig. 89.

water. The balance is immediately restored. We know that the capacity of the hollow cube is exactly equal to a cubic inch, and therefore we have a visible proof that a cubic inch of water—the quantity displaced by the cube D—weighs 252 grains; and dividing the known weight of the solid cube by 252 (2014 ÷ 252 = 8), we find that 8 is the specific gravity of the brass. What is true of a cube is true of all other forms of solids, however irregular.

335. *Specific gravity of liquids.*

The *specific gravity bottle* or *flask*, as it is called, furnishes a simple and accurate method of ascertaining the relative weights of equal volumes either of liquids or small solids, and thus of determining their specific gravities. It is simply a thin glass flask (see fig. 90), provided with a finely-perforated stopper and a counterpoise. The flask is carefully manufactured so as to hold, according to its size, 250, 500, or 1000 grains of distilled water at 62° F. The perforated stopper allows of the flask being perfectly filled. The specific gravity of any liquid is therefore at once determined by its weight. Thus the 1000 grain bottle filled with concentrated sulphuric acid will require 846 grains in addition to the counterpoise; and when filled with alcohol it will weigh 204 grains less than its counterpoise. Thus the weights of its volume of these liquids are 1846 and 796 grains respectively; and their specific gravities must be 1·846 and 0·796, that of water being taken as unity.

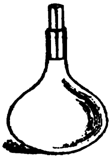
Fig. 90.

When there is but a small quantity of liquid, a 250-grain bottle must be used. Filled with benzoline at 62° F. its contents weigh 177 grains. Its specific gravity is thus 177 ÷ 250, or 4 × 177 ÷ 1000 = ·708. To get the specific gravity with the 250-grain phial, we have thus simply to multiply the weight of its contents by 4, and point off three decimal places.

The 1000 grain bottle is most convenient for finding the specific gravity of solids in powder or in fine grains, such as platinum grains, gold-dust, diamonds, rubies, and emeralds. The following is the result of an experiment on the native platinum grains from Siberia. The weight of the water in the bottle counterpoised at 62° was 1000 grains, and the weight in air of the platinum taken for the experiment was 40 grains. The united weights therefore were 1040 grains. On introducing the grains of platinum into the bottle, they displaced a quantity of water equal to their own bulk; and the bottle with the grains thus lost weight in proportion. A sufficient time was allowed for the free escape of air adhering to the metallic grains, and the bottle was again weighed. It was found to have lost exactly 2·5 grains by the displacement of water, which represented the bulk or volume of the platinum grains. The specific gravity was therefore obtained by dividing the weight of platinum by the weight of its bulk of water: $40 \div 2·5 = 16$, the specific gravity of Siberian platinum ore.

The lightest solid known is lithium, which has a specific gravity of 0·59, a metal which is a constituent of the alkali lithia. It is even lighter than any known liquid, for benzoline, the lightest liquid, has a specific gravity of 0·65, and on this the metal lithium will float like cork upon water (see Art. 329).

336. *Specific gravity of air or gases.*

This is ascertained by means of a glass globe or flask of known size, and furnished with a stopcock. It is first weighed when emptied by the air-pump, and afterwards when filled successively with water and with air or different gases. A comparison of the weights gives the specific gravities as already described.

337. As the volume of gases is more affected by heat than that of liquids and solids, it is necessary that their temperature should be accurately observed; and that the gases or vapours compared should be at the same temperature, or, if they differ in this respect, an allowance should be made according to certain known rules, so as to have both volumes at the same degree of the thermometer. Formerly air was taken as the standard or unit of density; and 100 cubic inches of it weigh, at mean temperature and pressure, 31 grains. It is found that 100 cubic inches of carbonic acid (or carbonic anhydride), under similar conditions, weigh 47·08 grains. Hence $47·08 \div 31$, or 1·520, is the specific gravity of carbonic acid. The lightest of all gases, hydrogen, is now generally adopted as the standard or unit of specific gravity; and as 100 cubic inches of hydrogen weigh only 2·14 grains, then $47·08 \div 2·14$, or 22, is the specific gravity of carbonic acid on the hydrogen scale.

338. Suppose we have to find the specific gravity of a solid lighter than water, such as cork. The cork is attached to a mass of metal or glass heavy enough to sink it, and already balanced in water for the purpose; and the buoyant effect of the cork, that is, the weight of its volume of water, is ascertained as before.

339. Suppose the solid is soluble in water—as a crystal of any salt. It may be protected during the operation of weighing in water, by previously dipping it in melted wax, so as to leave a thin covering on it; or it may be weighed in some liquid which does not dissolve it, allowance being made for the difference between the weight of such liquid and of water.

340. Suppose the solid in the form of powder. If insoluble in water—such as gold dust—it may be weighed in a glass cup previously balanced in water, but the specific gravity bottle serves better for this purpose (see fig. 90); and if soluble in water, it must be weighed in some other liquid, and a corresponding allowance made for the specific gravity of the liquid selected for the experiment.

341. *Hydrometers.*

A less delicate, though practically a more ready method of ascertaining specific gravities is by means of the contrivance called a hydrometer, or areometer. This dispenses with the use of the balance, which is a delicate instrument both to handle and to keep. Hydrometers have various forms according to the use to which they are to be put.

342. *Nicholson's Hydrometer* is that represented in fig. 91. It consists of a light glass balloon or hollow ball, *a*, bearing a light scale-pan, *b*, on a fine stalk, and carrying another cup, *c*, beneath. There is a mark on the stem to which the instrument sinks in pure water, when a certain weight (such as 1000 grains) is placed in the upper scale, *b*. This may be used to find the density of a solid, a small piece of brass, in this way. Put the brass into *b*, and add weights, say 40 grains, to sink the instrument to the mark *d*. We know thus that the brass weighs 960 grains. Next put the brass in the lower scale, *c*, leaving the 40 grains in the upper: the brass is buoyed up by the weight of its volume of water, and we must put say 120 grains more in the upper scale to counterbalance this. So 960 grains is the weight of the brass in air, and 120 grains is the weight of its volume of water; hence 960 divided by 120, that is 8, is the density of brass compared with water.

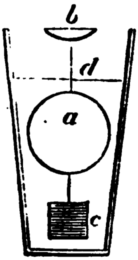

Fig. 91.

In using it for the specific gravity of liquids, the lower scale may be dispensed with, or retained merely to load the instrument and keep it upright. If it take, in addition to the weight of the hydro meter itself (2000 grains), 1000 grains to sink it to the mark in water, it will take different weights to sink it in other liquids. In sulphuric acid it will take 3400 grains; that is to say, 5400 grains is the weight of a volume of this liquid which weighs but 3000 grains in the case of water. Hence 5400 divided by 3000, that is, 1·8, is the specific gravity of the acid.

343. The most common uses of hydrometers are to indicate the specific gravity, and from that the strength or quality, of the distilled spirits brought to market, or of milk, or of saline mixtures. In these cases the special names *alcoholometer*, *saccharometer*, *lactometer*, *salimeter*, are often employed.

They are of various forms, but their general nature is the same in all. The instrument consists of a glass tube, loaded at the bottom with a little mercury to keep it upright, and graduated or marked with divisions, so that the specific gravity of any liquid may be read off at once from the depth to which the instrument sinks in it. In liquids lighter than water, the readings will obviously run *up* from the limit or water-mark; and in heavier ones, will run *down*. An ivory scale fixed to one kind of alcoholometer is marked P. S., for proof spirit, and the degrees above and below proof are indicated in figures by the exact level at which the instrument floats.

There are generally printed tables accompanying each instrument, telling the exact nature of its indications, and the allowances to be made for temperature and atmospheric pressure.

For ordinary commercial purposes, these are convenient and sufficiently precise; but they are by no means absolutely correct.

344. An old and ready method of finding the specific gravities of liquids was to have a set of small glass bulbs or *beads* of known weights, so that, when thrown into any liquid, those heavier than it will sink, those which are lighter will swim, while the one which just floats will mark its specific gravity. The bulbs are numbered once for all by the maker, so that the specific gravity is known at once by the figures upon them.

345. The following table shows the specific gravities of some common substances, referred to water as a standard:—

Solids:—		Arsenic . . .	5·96
Alum	1·70	Bismuth . . .	9·80
Aluminium . .	2·67	Brass	8·30
Amber	1·08	Charcoal (birch) .	1·36
Antimony . .	6·70	„ (oak) .	1·57

Coal	1·33
Coke	1·86
Copper	8·95
Diamond	3·50
Emery	3·95
Flint	2·60
Glass (flint)	3·33
Gold	19·34
Granite	2·70
Ice	0·92
Iceland spar	2·72
Iron (cast)	7·21
„ (malleable)	7·84
Ivory	1·92
Lead	11·36
Lime	3·18
Lithium	0·59
Magnesium	1·74
Manganese	8·01
Marble	2·84
Nickel	8·82
Phosphorus	1·83
Platinum	21·53
Pyrites (iron)	5·00
Silver	10·53
Sodium	0·97
Steel	7·81
Sulphur	2·05
Tin	7·29
Wood (ash)	0·84
„ (beech)	0·85
Wood (cork)	0·24
Zinc	7·15

Liquids:—

Acid (acetic)	1·06
„ (hydrochloric)	1·27
Acid (nitric)	1·517
„ (sulphuric)	1·848
Alcohol (pure)	0·815
Ammonia (solution)	0·875
Benzoline	0·65 to 0·71
Beer	1·023 to 1·034
Bromine	3·187
Carbon disulphide	1·272
Chloroform	1·5
Ether (sulphuric)	0·724
Mercury	13·596
Milk (cow)	1.03
Naphtha	0·86 to 0·90
Oil (olive)	0·918
Water (pure distilled)	1·000
„ (rain)	1·001
„ (sea)	1·026
„ of the Dead Sea in Palestine	1·160
Wine	0·99 to 1·038

Gases:—

(Hydrogen = 1.)

Air	14·4
Ammonia	8·5
Arsenic vapour	150·0
Carbonic acid	22·8
Chlorine	35·5
Coal gas (about)	7·2
Iodine vapour	127·0
Mercury vapour	100·0
Nitrous oxide	22·0
Nitrogen	14·0
Oxygen	16·0
Steam	9·0
Sulphurous acid	32·0

A cubic foot of water weighs very nearly 1000 ounces avoirdupois, or 62½ lbs. Hence the specific gravities of solids and liquids in the foregoing table have only to be multiplied by 1000 to give the weight in ounces of a cubic foot of the different substances.

Thus gold will contain 19,340 ounces in a cubic foot, being worth in money about £63,000 sterling; and a cubic foot of marble will weigh 2·84 × 1000 = 2840 ounces, or about 180 lbs. A cubic foot of ice, which has a specific gravity of 0·92, will therefore weigh (0·92 × 1000) 920 ounces, which at once shows how much ice is lighter than its bulk or volume of water. A cubic foot of common air contains only about one ounce; while a cubic foot of hydrogen gas (the lightest substance known) contains less than a drachm.

Atmospheric air is thus about $\frac{1}{840}$th part of the weight of water: and hydrogen only $\frac{1}{12000}$th part.

SECTION II.—HYDRAULICS, OR THE PHENOMENA OF LIQUIDS IN MOTION.

ANALYSIS OF THE SECTION.

The necessity of a plentiful water-supply to the animal and vegetable world renders the study of the laws of flowing liquids both interesting and useful. Water issuing from a vessel, or passing through pipes or channels, is regulated in its flow by the height of its source, and by the friction or resistance it meets on its way. The currents of rivers and the waves of the sea are thus brought under the laws of hydraulics. In naval architecture, the resistance of water to the motion of bodies immersed in it has to be carefully considered. On the other hand, the resistances that moving liquids are able to overcome lead to the employment of the fluid motions in nature as a source of work-power; as, for example, in water-wheels, water-engines, &c., as well as in raising water to a height for domestic purposes and for irrigation.

Hydraulics.

346. The special interest that, increasing with the advance of civilization, attaches to the distribution of water and the laws of flowing liquids which have to be observed for the purpose of such distribution, arises from the fact that, without a copious supply of pure water, life in large towns and cities would be insupportable, and the vast accumulations of human beings in the great capitals of modern times—Paris, New York, Berlin, Jeddo, and London—would become but so many plague-spots on the surface of our globe.

It was from the want of suitable material for the construction of pipes or conduits, and not from ignorance of the value of a plentiful water-supply, that the ancients were so little advanced in hydraulic engineering. Recourse was had to open canals, of which numerous traces remain on the banks of the Tigris and Euphrates, indicating the existence of a regular system of water distribution through the gigantic capitals of Assyria and Babylon.

In Phœnicia, in Judæa, in Egypt, there are numberless ruins of aqueducts, tanks, and wells; but the most magnificent examples of artificial watercourses were the aqueducts of ancient Rome. About 300 B.C. the first aqueduct was completed, and by the later days of the empire there were as many as twenty, distributing to the Eternal City a daily supply exceeding sixfold the quantity allowed per head to the population of modern London. Their domestic consumption averaged probably much the same per head as that of our large cities—forty gallons a day; but it is a most remarkable fact that the great bulk of the water was devoted to their public fountains, baths, gardens, and amphitheatres. Several of the Roman aqueducts exceeded forty miles in length, passing through hills in their way, and resting on tiers of splendid arches across the valleys. These were copied in other parts of the empire; and even in later times there are several examples—such as the Lisbon aqueduct (1713–32), the Croton aqueduct of New York, and others—of waterworks designed upon the principle of the ancient Romans.

In modern times, the applications of the arts have completely changed the conditions of the problem to be solved for the distribution of water, and have rendered a thorough acquaintance with the physical principles to be attended to in all such undertakings a matter of the greatest consequence.

"*Fluids issuing from vessels, or moving in channels.*"

347. It is an important, though apparently paradoxical fact, that the force required to drive a certain quantity of water through a certain opening in a given time, must be increased fourfold instead of twice, to drive double the quantity through the same or a like opening, in the same time. Thus, if, in a vessel of water, A (fig. 92), a small hole be pierced in the side at *b*, a foot below the surface of the water, the pressure of liquid there will cause a certain quantity, say a gallon, to spout forth in one minute; but, in order that two gallons may issue in the same time from a similar opening below, that opening must be made not at two, but at four, feet below the water surface. Again, if a quantity of water be squirted from a syringe, or force-pump, by a force of one pound pressing the handle of the piston, a

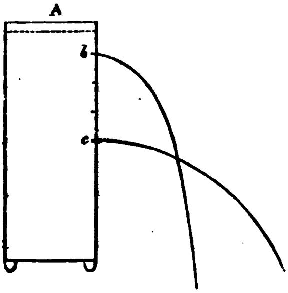

Fig. 92.

force of four pounds would be required to double the quantity of the discharge in the same time.

The reason of such facts is, that the double number of water particles moved would require double force if they were moved with only the same velocity; but because twice as many have to pass through the same sized opening in the same time, each must move with double speed, requiring another doubling of the force on that account, and the two doublings make a fourfold increase. So, in order to force a triple discharge, the power employed must be nine times as great; to force a quadruple issue it must be sixteen times as great; and so forth, in the proportion of squares.

348. Another phenomenon illustrates the same principle. If a tube be screwed into the lower part of a water cistern, B (fig. 93), and have its outer end turned up as a spouting nozzle, *c*, the water will jet upwards to the height of the water surface in the cistern, with a certain deduction for the resistance of the air and friction. Hence, by the law of falling bodies, the velocity of issue at *e* must be the same as that acquired by the liquid falling from the level of its surface. Thus, we may learn the velocity of the issue of water from the side or bottom of a reservoir in any case, and therefore, approximately, the quantity delivered through a pipe or opening of a given size.

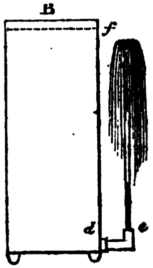

Fig. 93.

349. It is a curious fact that more water issues from a vessel with thin sides through a short pipe, than through a simple aperture of the same diameter in the thin side—and still more if the pipe be funnel-shaped within, or a little wider towards its inner extremity. The explanation is, that the particles coming from all sides of the opening to escape, cross and impede one another in rushing through a simple opening, as proved by the narrow neck called the *vena contracta*, which the jet exhibits a little beyond the opening; but in a uniform tube, this narrowing of the jet could not happen without leaving a vacuum around the part, and the pressure of the atmosphere, preventing the formation of such vacuum, causes a quicker flow. The funnel-shape again leads the water by a more gradual inclination to the point of exit, and prevents the crossing among the particles which retards the flow; moreover, seeing that its external mouth surrounds the narrow neck of the jet, that part may be considered the commencement of the jet.

350. Another remarkable effect of atmospheric pressure on flowing liquids is, that if the channel be a tube of considerable length descending from a reservoir, it materially quickens the discharge. Water naturally falls like any other body with accelerating velocity; but if it so fall in a tube which it fills like a piston, either portions of it below must outstrip what is above, leaving vacuous spaces between, or water from above must be pressed more powerfully into the tube by the atmosphere to prevent a vacuum. The increased forcing in of the water at the top of the tube by the atmosphere causes that depression of the water-surface in the reservoir over the tube, which becomes very conspicuous as the depth in the reservoir diminishes.

351. The resistance which fluids suffer in passing along pipes depends partly on the cohesion and friction of the particles among themselves, but more on friction against the pipe; the particles near the tube being constantly driven from their straight course by the irregularities in its surface. A tube of an inch diameter and 200 feet in length, placed horizontally, is found to discharge only a fourth part of the water which escapes by a very short pipe of the same diameter. Air or gas also in passing along tubes is much retarded. Some one erected a great bellows at a waterfall, to blow a furnace two miles off, but found that his apparatus was almost useless. When gaslights were first proposed, some engineers feared that the resistance from friction to the passing gas would be fatal to the enterprise. Abrupt bends, in a tube or pipe conveying liquids, retard the rate of discharge very considerably; and where these are numerous and unavoidable, as in the distribution of water through a city, due allowance must be made for this cause of resistance.

352. Higher temperature in a liquid increases remarkably the quantity discharged by an orifice or pipe; doubtless, by diminishing the mutual cohesion of the particles, and increasing their mobility and fluidity. The addition of 100 degrees of heat will in certain cases nearly double the discharge.

353. The flowing of water through orifices under uniform circumstances is so steady, that before the invention of clocks and watches, it was employed as a means of measuring time. These instruments were called *clepsydræ*. That of Ctesibius* is famous, in which the water issued as tears from the eyes of a figure standing and deploring the passage of time. The tears gradually filled a vessel, and raised another floating figure, which pointed to the hours marked on an upright scale. This vessel daily emptied itself by a syphon, at the moment when the water reached a certain height, and the discharge of the water worked mechanism which told the month and the day. The flow of sand, in the common *sand-glass*, is analogous to that of the water in the *clepsydra*.

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* A Greek philosopher and mechanician who lived at Alexandria about 250B.C.

354. The flow of rivers is very materially retarded by friction. But for this, a river drawing its waters from an elevation of only 1000 feet above the level of its mouth would pour them out with the velocity of water issuing from the bottom of a reservoir 1000 feet deep; that is to say, at the rate of about 170 miles per hour. The ordinary flow of rivers is from three to five miles per hour, and their channels slope from three to five inches per mile.

In a sloping channel connected with a reservoir of water, the stream will gain speed as it flows, like a ball rolling down an inclined plane; and at the point where it has double speed, the channel will be only half full. It is evident that two such channels might meet, and the contents of both would then only fill a single channel of the same size. Persons not reflecting on the increase of speed due to declivity often express surprise to see how small a drainage pipe can carry off a large quantity of fluid. This explains also why a mountain stream having various degrees of declivity may appear of strangely different size in different parts of its course.

355. The velocity of a stream may be ascertained by immersing in it an upright tube, of which the bottom bent at right angles becomes an open mouth turned towards the stream. The water in the tube will stand above the surface of the stream, as much as would be necessary in a reservoir, according to the explanation given above, to cause a velocity of jet equal to that of the stream. A modification of this contrivance may be made to measure roughly the force and velocity of the wind. The more obvious mode of telling the velocity of an open stream, is to observe with a stop-watch the progress of any light floating body where it can be followed for a certain distance; and the average speed and the dimensions of the channel being known, the quantity delivered in a given time becomes a matter of simple calculation. So the speed of the wind may be readily ascertained by observing how long the shadow of a cloud takes to pass across a field of known dimensions.

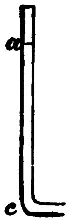

Fig. 94.

356. The friction of water moving in water is such, that a small stream directed through a pool, with speed enough to rise over the opposite bank, will soon empty the pool. The friction between air and water is also singularly strong, as is proved on a great scale by the magnitude of the ocean-waves, which are consequences of it. Oil thrown upon the surface of water soon spreads as a film over it, and defends it to a considerable degree from the contact and friction of the air, making it too smooth for the air to act upon it.

357. A stone thrown into a smooth pond causes a succession of circular waves to spread from the spot where it falls as a common centre. They become of less elevation as they expand, until gradually the liquid mirror becomes again perfect as before. Several stones falling at the same time in different places cause crossing circles, which, however, do not influence the progress of one another otherwise than by increasing the heights and hollows at the points of their meeting. The rationale of these waves is as follows. When the stone falls into the water a part of it is displaced laterally, and becomes an elevation or circular wave around the stone. This outward motion is transmitted in obedience to the laws of fluidity, already explained, and the circle widens. In the meantime, where the stone descended, a hollow is left for a moment in the water, but, owing to the surrounding pressure, is soon filled up, chiefly by a sudden upheaving from below. The rising water does not stop, however, when it has reached the general level of that around, but, like a pendulum sweeping past the centre of its arc, it rises almost as far above the level as the depression was below it. This central elevation now acts as the stone did originally, and causes a second wave, which pursues the first; and when the centre subsides again like the pendulum, it sinks again almost as much below the level as it had mounted above that; hence it has to rise again, again to fall, and so on for many times, sending forth a new wave at each alternation. Owing to the friction among the particles of the water, each new wave is less raised than the preceding, and at last the appearance dies away. But so mobile is a liquid surface that a disturbance at any part extends to great distances. In seas liable to sudden but partial hurricanes, the noise of breakers on the shore may tell of a distant storm which does not otherwise announce itself.

A wave passing through any gap or opening spreads from it as a new centre; and a wave coming against a perpendicular surface of wall or rock is completely reflected from this, and acquires the appearance of coming from a point as far beyond the reflecting surface as its real origin or centre is distant on the side where it is moving.

The common cause of waves is the friction of the wind upon the surface of the water. Little ridges or elevations first appear, which, by continuance of the force, gradually become loftier and broader, until they are the rolling mountains seen where the winds sweep over a great extent of water. The heaving of the Bay of Biscay, or still more remarkably, of the open ocean beyond the southern capes of America and Africa, exhibits one extreme; and the stillness of the tropical seas, which are sheltered by near encircling lands, exhibits the other. In rounding the Cape of Good Hope, waves are met with, or rather a swell, so broad, that a few ridges and a few depressions occupy the extent of a mile. But these are not so dangerous to ships as what is termed a *shorter* or more abrupt sea, with steeper waves.

358. The velocity of waves has relation to their magnitude. The large waves just spoken of proceed at the rate of from thirty to forty miles an hour.

It is a vulgar belief that, in waves, the water itself advances in the direction, if not with the speed, of the wave, but in fact the *form* only advances, while the *substance*, except a little spray above, remains rising and falling in the same place, with the regularity of a pendulum. A wave of water, in this respect, is closely imitated by the wave-form running along a stretched rope when one end is shaken, or by the mimic waves of our theatres, which may be undulations of long pieces of carpet. But when a wave reaches a shallow bank or beach, the water becomes really progressive, for then, as it cannot sink directly downwards, it falls over and forwards, seeking the level.

The excited imagination pictures the waves of the ocean as loftier than they really are. Few, if any, waves rise at their crest more than fifteen feet above the ordinary sea-level, which gives thirty feet for the whole height, from trough to crest. This is easily verified by observing at what height on a ship's rigging the horizon remains always in sight over the top of the near waves—allowance being made for accidental inclinations of the vessel, and for her sinking considerably below her water line, when she reaches the bottom of the hollow between two waves. The spray driven along by the violence of the wind may, of course, rise much higher than the summit of the liquid wave; and a wave coming against an obstacle may dash to an elevation much greater still. At the Eddystone lighthouse, reared on a solitary rock ten miles from the land, a wave which has been growing from far across the Atlantic often dashes above the lantern at the summit, which is about ninety feet high.

The magnitude of waves is well judged of when they are seen breaking on an extended shore or beach. In the deep sea the wave is only a moderate elevation of the water, sloping on either side; but as it rolls towards the shore, its front becomes more and more perpendicular, until at last it curls over and falls with its whole weight, and when several miles of it break at the same instant, its force and noise seem to shake the country around.

359. When the flood-tide returning from the sea meets the outward current of a river, which falls into an estuary narrowing by degrees, the stronger mass from the ocean assumes the form of an almost perpendicular wall, moving inland with a resistless sweep. The wave-like elevation which is produced by the meeting of the waters is called the *Bore.* In the branches of the Ganges the bore is seen in a remarkable degree. Its roaring is heard long before it arrives. Smaller boats and skiffs cannot live where it comes, and have therefore to be drawn up on the shore; and as it passes the city of Calcutta, even large ships at anchor there are thrown into commotion. At Calcutta there is sometimes an instantaneous rise of five feet, and this huge wave advances at the rate of about fifteen miles an hour. In the channels at the mouth of the River Brahmapootra, the height of the bore is said to exceed twelve feet, and to be most terrific in appearance, and so dangerous that no boat will venture to navigate at spring tide the channels between the islands at the mouth of that river. The nature and effects of this strong flood-tide are strikingly illustrated upon certain coasts where extensive tracts of sand are left uncovered at low water. In such situations, of which there are several on the western shores of Britain, as Morecambe Bay and the Solway Firth, the returning tide is seen advancing with such rapidity, that the speed of a galloping horse can scarcely save a person who has incautiously approached too near.

"*Fluids resisting the motion of bodies immersed in them, or themselves moving forcibly against other bodies.*"

360. The same force is required to give, or to take away, motion in a fluid, as in an equal quantity of solid matter. A pound of water inclosed in a bladder is not more easily thrown to a given height than a pound of ice, or of lead; nor, if falling into the scale of a weighing beam, does it require less as a counterpoise; nor, if made to revolve at the end of a sling, does it render the cord less tight.

361. The force of water moving against an obstacle, or of the resistance of still water to a moving solid, may be deduced from the fact that the pressure of a known height of fluid column produces from an orifice a certain velocity of jet; while conversely, that jet, or any current of equal speed directed against the orifice, supports the column. The impulse given or received, therefore, by the float-board of a water-wheel, whether of a steam-boat pressing against, or of a corn-mill pressed by, the water, is measured by the weight of a column whose height is according to the velocity, and whose diameter is according to the breadth or extent of the surface concerned. This supposes that the liquid pressure of, or upon, the surface is direct; if it be oblique, there is a diminution according to the rule given under the head of "resolution of forces."

One might expect that if a body, as a boat, moving through water at a given rate meet a given resistance, and cost a given expenditure of energy, it should just meet double resistance, and cost double energy when moving twice as fast. But the resistance and energy, with a double rate, are more than four times greater.

These facts are but additional examples of a principle already explained (Art. 347). A boat which moves one mile per hour displaces or throws aside a certain quantity of water with a certain velocity. If it move twice as fast, it displaces twice as many particles in the same time, and requires to be moved by twice the force on that account; but it also displaces every particle with a double velocity, for twice as many have to be pushed aside in the same time, and it requires another doubling of the power on this account. In the same manner a ninefold energy is required for a triple speed, three times as many particles being moved, and each particle with three times the velocity. For a speed of four, an energy of sixteen; for a speed of five, an energy of twenty-five; and so forth. The relation is that which mathematicians indicate by saying that *the resistance increases as the square of the speed.*

Thus, if the resistance at the bow of a vessel were all that had to be considered, one hundred horses would drag the vessel ten times as fast as one horse. But another important element in the calculation farther increases the disparity between the visible motion and the energy expended, viz., the lessening of the water-pressure on the stern, as the speed of the vessel increases. This pressure, while the vessel is at rest, is just equal to the pressure on the bow; and the energy therefore required to increase the velocity is still considerably greater than in proportion to the square of this velocity.

362. This fact is of very great importance, and explains at what a heavy expense of fuel and machinery high velocities are obtained in steam-boats. If an engine of about 50-horse power would drive a ship seven miles an hour, two engines of more than 50, or one of more than 100, would be required to drive it ten miles, and three such to drive it twelve miles; even supposing the increased resistance at the bow, as already stated, to be the measure of the whole work to be done, which it is not, and that engines worked to the same advantage with a high velocity as with a low, which they do not. For the same reasons, if all the coal which a ship could conveniently carry were just sufficient to drive her 1000 miles at the rate of twelve miles per hour, it would drive her more than 3000 at a rate of seven miles per hour; and more than 6000 at a rate of five miles per hour.

The same law shows the error of putting very large sails on a ship. The trifling advantage in point of speed by no means compensates for the additional expense of making and working the sails, and the risk of accidents in bad weather. The ships of the prudent Chinese have not, for the same tonnage, one-third so much sail as those of Europeans, and yet they move with sufficient speed for many purposes. A European ship under jury-masts, or makeshifts after a storm, does not lose nearly so much of her usual speed as one might expect.

This explains also why a ship glides through the water one or two miles an hour with a very little wind, although with a strong breeze she would only sail at the rate of six or eight miles. Less than the 100th part of that force of wind which drives her ten miles an hour will drive her one mile an hour, and less than the 400th part will drive her half a mile. Thus, during a calm, a few men pulling in a boat can move a large ship at a sensible rate.

363. These considerations show strikingly of what importance to navigation it might be to have, as a part of a ship's ordinary equipment, one or two water-wheels (or ready means of forming them), to be affixed upon the ship's side when required; so that, by working these in connection with the capstan, the tedium, expense, and even disastrous results of a long calm at sea might be avoided. A pair of such wheels might also serve other purposes; for, when acted upon by the water as the ship sailed, they would turn with the force of water-wheels on shore, and might be made to move the pumps, to hoist the sails, and to do any work which a steam-engine could perform. Many a vessel has perished because the exhausted crew could no longer labour at the pumps, where such water-wheels would have performed the work required for a much longer time.*

364. The law, that resistance to a body moving in a fluid increases in a greater proportion than the speed of the body, applies where the fluid is aëriform, as well as where it is liquid.

A bullet shot through the air with a double velocity, for the reasons given above, experiences four times as much resistance in front as with a single velocity; the motion being retarded also by the loss or diminution on the posterior surface of the usual atmospheric pressure of 15 lbs. per square inch. It is true, further, that when the velocities of bodies moving in air are very great, the resistance in front increases in a still quicker ratio than in liquids; and possibly because the compressibility of air allows it to be much condensed, or heaped up, before the quick moving body. This will be again referred to.

365. The rule of action between a solid and fluid now explained is reciprocal, and holds the same when the fluid is in motion against the solid, as when the solid moves through the fluid.

If a ship be anchored in a tide's way, where the current is four miles an hour, the strain on her cable is not one-fourth part so great as if the current were eight miles.

A wind moving three miles an hour is scarcely felt; if moving six miles, it is a pleasant breeze; if twenty or thirty miles, it is a brisk gale; if sixty, it is a storm; and beyond eighty, it is a frightful hurricane, tearing up trees by the roots, and generally destructive.

Supposing the wind to move one hundred miles per hour, there are one hundred times as many particles of matter striking any body exposed to it as when it moves only one mile per hour, and each particle strikes, moreover, with one hundred times the velocity or force, so that the whole increase of force is a hundred times a hundred, or ten thousand. This explains how the soft invisible air may, by motion, acquire force sufficient to unroof houses, to level oaks, the roots of which have been spreading wide and gathering strength for centuries, and, in some forms of hurricane, absolutely to brush away everything projecting from the surface of the earth. The explosive force of ignited gunpowder illustrates the same principle.

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* The suggestion here made was acted upon a year after the publication of the first edition of this work.

366. This law of rapidly increasing resistance assigns a limit to many velocities, both natural and artificial.

It limits the velocities of bodies falling through the air. By the law of gravity a body would fall with a constantly accelerated speed; but as the resistance of the air increases still more quickly than the speed, at a certain point, this resistance and the gravity balance each other, and the motion becomes uniform.

No ship under canvas or with steam power sails faster than about twenty miles an hour; and it is because the frictional resistance to be overcome by steam-carriages on railways does not increase with their velocity, like the water resistance to ships, that the speed of the former may so much exceed that of the latter.

No fish swims with a velocity much exceeding twenty miles an hour; not the dolphin, when shooting ahead of our swiftest frigates; nor the salmon, when darting forward with the speed that lifts it over a waterfall.

367. The resistance between a meeting fluid and solid depends greatly on the *shape* of the solid.

Experiment shows that a *round* mass of wood floating in water can be drawn along at a certain rate by about half the force required to draw a *cubical* block of the same material and of the same diameter and weight. As a plough opens and penetrates the ground with ease proportioned to the sharpness of its wedge-like form, so does the wedge-formed ship plough easily through the water. In the case of the plough, the furrow left behind remains open, and the form of the hind part of the plough is immaterial; but in the case of the ship, the water has to close in behind, and by its pressure to counterbalance in a degree the resistance of the water in front. If the stern part of a ship were to be abrupt like the end of a packing case, the water would fall in but slowly to fill up the furrow called the ship's wake, and hence would arise an important cause of retardation. To favour, therefore, the motion of a ship through the water, the wedge-shape or tapering is required behind as well as before; a gradual tapering of the hind part, or a *fine run*, as it is technically called, allows the water to apply itself readily to it as it passes along, and is essential for quick sailing.

368. Nature herself furnishes us with the models of our sailing vessels. Fishes are wedge-like both before and behind, their form being modified, however, in relation to other purposes of equal importance to them as mere speed of motion. Of birds the same is true, and in flying they are observed to stretch out their necks, so as to make their form perfect for dividing the air. There are boats used in China called *snake-boats*, seen on festive occasions, which are only about two feet broad, while perhaps a hundred feet long, and when they are moved by a multitude of rowers, their swiftness is extreme. The problem which has for its object to assign for a ship's hull or bottom the best possible form to give speed of sailing with capacity for cargo, is of much importance, but, being of very great complexity, is not yet satisfactorily solved; so that a kind of empiricism prevails in the matter, and unexpected results often arise.

The flight of birds through the thin air has a limited celerity. The crow, when flying homewards against the storm, does not face the wind in the open sky, but skims along near the surface of the earth in the deep valleys, or wherever the swiftness of the wind is retarded by terrestrial obstructions. The great albatross of the South Sea, stemming upon the wing the current of a gale so as to remain in company with a driving ship, where the air is passing at the rate of eighty miles an hour, often takes short shelter on the lee side of a lofty billow. The bird called the *stormy petrel* abides chiefly in the midst of the Atlantic Ocean, but the violence of the wind can sweep it from the waves and cause its appearance on the solid shores. Vessels from the high sea, approaching a coast from which strong wind blows, often become resting-places to exhausted land-birds, driven off the shore by wind which they have not strength of wing to stem;—sad evidence of the myriads which are constantly perishing where no resting-place is found, and where no eye notes their fate.

369. The following instances exhibit the mutual influence of meeting solids and fluids, where the surface of the solid is plane or slightly concave. In a water-wheel, whether the water is the moving power, as where a stream acts to drive machinery, or the resistance, as in the case of the paddle-wheels of a steam-boat, the impulse on the flat faces of the vanes or float-boards is proportioned to the area. When a wheel with float-boards has its lower part merely dipping into a stream of water, to be driven by the momentum of the water as it floats along, it is called an *undershot wheel.* When the water reaches the wheel near the middle of its height, and turns it by falling on the float-boards of one side, as they sweep downwards in a curved trough fitting them, the weight of the water also is called into play ; and this modification is called a *breast-wheel.* When the float-boards are shut in by flat sides, so as to form cavities or buckets round the wheel, into which the water is allowed to fall at the top of the wheel, and to act almost by its weight only, the modification is called the *overshot wheel.* To have a maximum of effect from wheels acted on by the moving force of water, they are generally made to turn with a velocity about one-third as great as that of the water ; and wheels moved by the simple weight of water usually have their circumference turning with a velocity of about three feet per second. The subject of water-wheels is one of the most important in practical mechanics ; seeing that, where water power is supplied ready to hand, it would be useless waste to employ steam power.

Oars for boats are made flat, and often a little concave, that the water may be prevented from sliding off the oars, and the mutual action between them and water may be as great as possible. The webbed feet of water-fowls are oars : in advancing they collapse like a shutting umbrella, but open outwards in the thrust backwards, so as to offer a broad concave surface to the water. The sails of ships, when they are receiving a fair wind, are seen to bulge or swell a little, and are supposed thereby to receive a stronger impulse.

370. The resistance between a meeting solid and fluid being nearly proportioned to the breadth and surface of the solid, it follows that *large* bodies, because containing much more matter, in proportion to their breadth and surface, than smaller bodies of similar form, are less resisted, in proportion to their weights, than smaller bodies.

The science of measure tells us that a bullet, or other regular solid, of two inches diameter, has eight times as much matter in it as a similar solid of one inch diameter, while it has only four times the surface. If, therefore, a bullet of eight pounds, and a bullet of one pound, be shot off with equal velocity, the larger has only half as much surface in proportion to its weight, and therefore in proportion to its momentum, as the other. Consequently, it will go much further against the resistance of the air than the other.

For this reason large spherical shot, smaller cannon-balls, musket-bullets, pistol and swan-shot, and the common small-shot of the sportsman, all discharged with the same velocity, have always a shorter range as they are smaller in size. Even water is sometimes thrown from a gun or powerful syringe to stun birds, that they may be obtained with uninjured plumage; but as it soon divides very minutely in the air, it reaches only to a short distance.

371. Water, falling through the air from a great height, goes on suffering a gradual division into smaller and smaller portions, which at last may be said to be nearly all surface; and these are then seen sinking slowly as a mist. The different sizes of rain drops are explained partly by the height from which they have fallen, and partly by the amount of atmospheric disturbance during the fall. In calm weather, with the clouds near the surface of the earth, as during a thunderstorm, for example, the drops are very large and heavy compared with their size on a wet, windy day. The toy called the *water-hammer* is merely a small quantity of water hermetically inclosed in a tube which is exhausted or empty of air: when, by turning the tube, the water is made to fall from one end to the other, as there is no air to break up its cohesion, it falls as one mass, and makes a sharp noise like the blow of a hammer.

372. The largeness of the surface in proportion to the quantity of solid matter, explains why a spider's thread or a single filament of silk floats so long in the air before it falls; why there are almost constantly suspended in the air those very minute particles which appear as motes in the sunbeam; and there is reason to believe that the insidious transporters of infectious diseases are often invisible particles, wafted, it may be, great distances from their putrid source; why the fine dust, sent aloft during the eruption of volcanoes, is often carried by the wind to a distance of hundreds of miles; why, in the deserts of Africa, the strong winds often transport fine sand from place to place, overwhelming caravans, and forming new mountains, which succeeding blasts are again to lift; why, in the bottom of a river, or in a tide's way, fine mud is found only where the current is slow, sand where it is quicker, pebbles or large stones where it is quicker still, while in rapids and waterfalls only massive rocks can resist the fluid force. The explanation of the floating of clouds in the atmosphere, which is very much lighter than the watery particles forming the clouds, is not very apparent. It seems probable, however, that the support required to keep them afloat is in part due to aërial currents underneath, in somewhat the same way as the motion of a fan supports the toy known as the Japanese butterfly.

373. A like explanation may be given of the operation of *levigating*, by which heavy substances, insoluble in water—such as the emery used in polishing—are obtained in the state of the finest powder. Any such substance is first ground or powdered in the ordinary way, and then diffused in a vessel of water. The grosser parts first fall to the bottom, and if the water be then passed into another vessel, the deposit in that will be of smaller portions ; in a third vessel, with longer time allowed for subsidence, the deposit will be of smaller particles still, and so on, if desired. The fine powder of flint used in the manufacture of porcelain is obtained by levigation, as is also that of putty powder, calamine, whiting (chalk), and other powders used in medicine and in the arts.

The power of running water is seen in the rapid destruction of embankments, if the water be allowed to accumulate and run over the top. The particles of the earth or clay on the top, while dry, press on one another with all their weight, and form a tolerably resisting barrier ; but if the water reach them, they half float, and are so easily carried along by the powerful friction of the passing water, that a small channel or gap is quickly rendered the outlet of a resistless torrent. Where rivers, like the Po in Lombardy, have in many places to be retained in their channels at a higher level than the surrounding fields by earthen banks, a small gap cut in the embankment might flood the whole of the low country. Some disastrous cases have occurred in the fen districts of England by failure of embankments or sluices.

374. Thus, by means of air or water, substances of different specific gravities in mixture may be easily separated. If pieces of cork and lead be let fall together through the air, the lead will reach the ground first, and may be swept away before the cork arrives. So the farmer, by *winnowing* in either a natural or artificial current of air, readily separates the grain from the chaff, and, if he desire it, may even divide the grain itself into portions of different quality. Similar to this is the operation of separating sand or mud from gold-dust by water. A current of water made to pass over the soil containing gold-dust, carries away the lighter rubbish, and leaves the gold. A lead ball with a string attached to it, an arrow loaded at the point, or a shuttle-cock with its cork and feathers, always moves with the heavier mass in front, because the resistance of the air has least influence on the greater momentum.

" *Oblique fluid action.*"

375. When a fluid and a solid meet obliquely, the resultant impulse is still perpendicular to the surface of the solid, as if they met directly, but is less forcible as the obliquity of the approach is greater.

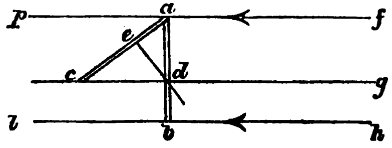

Fig. 95

Suppose the double line, *a b* (fig. 95), to represent the edge of a smooth board placed in a current of fluid running with a certain speed in the direction of the lines with arrow points, *f p* and *h l*; the pressure on the board will be direct or at right angles to the board, and proportioned to the area of the surface. If then the board be placed obliquely to the current, in the position, *a c*, evidently the breadth of current acting on the board will be as much less than previously as the line, *a d*, is shorter than the line, *a b* (mathematically stated, the line, *a d*, is called the sine of the angle of obliquity—(*See the Appendix*). Then, further, the part of the current striking the board, and reduced to the breadth, *a d*, strikes it not directly but obliquely, and therefore only with force represented by the line, *a e*, instead of *a d*. (See Art. 130.) That line, *e a*, is again the sine of the angle of obliquity, with the line, *a d*, for radius.

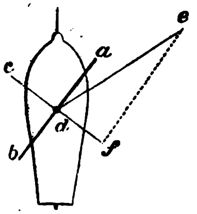

Fig. 96.

376. From this it appears that the wind blowing upon the sail of a ship, however obliquely, as from *e* to *d* (fig. 96), always presses it directly, or perpendicularly to its surface, with a part of its force. If the wind approaching the sail, *a b*, be represented, as to direction and strength, by the line, *e d*, it will act on the sail as if it came from *f*, but with a force smaller in the proportion of *f d* to *e d*. The effect, therefore, is the same as if the sail were pulled by a rope, *d c*. And all the sails being adjusted so as to receive the wind in the direction here shown, a little behind their back-surfaces, they all act to produce the same result as if pushes were made in the direction, *f d*, or as if ropes were pulling from each in the direction, *d c*, or parallel to it. Now the side force, *c d*, would urge the vessel sideways, as well as forwards, were it not that the form of vessels causes them to pass forward at least twenty times more easily in the direction of their sharp bow, than sideways across their broadside or keel. Thus a force urging equally sideways and forwards causes a ship to advance twenty miles in the direction of her keel for one mile which she deviates sideways. The deviation sideways, which in sailing-vessels must take place to a certain extent whenever the wind is at all oblique, is called the *lee-way*.

A vessel having to sail from *b* to *a*, while the wind blows directly against her course, or from *a* to *b*, is obliged to sail *close to the wind*, as represented in last paragraph, first, it may be supposed, to *e*, as represented in fig. 97, with the left or larboard side to the wind, then to *tack*, as it is called, or turn round, at *e*, and to sail to *d*, with the right or starboard side to the wind; then to go on the larboard tack again to *c*, and thence to port at *a*. A ship tacking, as here represented, makes an approach of one mile towards her port for about two which she sails through the water.

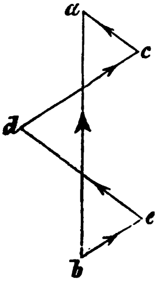

Fig. 97.

In making way against a *contrary wind*, the sails of a ship have to be pointed so nearly edgeways to the wind, that, unless very flat, a portion of their surface becomes useless. The Chinese manner of rigging has, in this respect at least, some advantages, for in it bamboo reeds attached across the sails render these as flat as boards.

A ship with several masts may sail faster when the wind is more or less from a side, than when directly astern, because in the former case all the sails are acting, although not to the best advantage individually, while, in the latter, the sails in front are becalmed by those behind them. With a side wind, a ship may move a little faster than the wind itself, as is often the case with the outer extremities of a windmill's vanes.

377. Oblique fluid action is well illustrated by the action of the *rudder* of a ship, which enables a single man to direct the course of a huge vessel before a stormy wind. The helm or rudder is a sort of door or gate hanging by strong hinges from the stern-post of the ship, and moved by a lever called the *tiller*. In small vessels the tiller is above the deck, and the steersman applies his hand directly to it; but in large ships it is below, and is moved by ropes or chains leading to the axle of *the wheel* on the deck, where the steersman stands with the compass before him. While the rudder points directly astern, as shown by the line *a*, it does not affect the vessel's course; but if it be inclined ever so little to one side, as is the line, *b*, on the left or *larboard* side, the water offers greater resistance in the direction, *c b*, and the stern moves to the right or *starboard* side—an action equivalent to pulling the bow to the left or larboard.

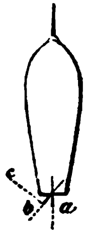

Fig. 98.

378. A ship or boat might be made to steer itself, by placing a powerful vane on the mast-head, and connecting that with the tiller-ropes by two arms projecting from its axis. To make the ship sail directly before the wind, the tiller-ropes would have to be connected with the arms of the vane so that the helm should be in the middle position when the vane was pointing directly forward. Should the vessel then by any cause deviate from her course, the vane by its changed position with respect to her keel, would produce a corresponding change on the position of the helm, just such as to bring her back to her course. By adjusting such a vane and rudder to each other in different ways, any other desired course might be obtained, which would alter only with the wind. The vane, to have the necessary power, would require to be of large size—a wide hoop, for instance, with canvas stretched upon it; and the rudder, to turn with little force, might be hung on an axis passed nearly through its middle, instead of, as usual, by hinges at one edge. So long as the wind kept the same direction, the course of the vessel might in this way be exactly prescribed beforehand.

379. As fluids act on surfaces in a direction perpendicular to them, the water on the right side of a ship's bow is always pressing it towards the left side; but owing to the equivalent and contrary pressure on the left side, the ship holds her course evenly between the two, or straight-forwards. When a ship, however, owing to a side wind, lies over or *heels*, as it is called, that side of the bow which sinks most is more pressed than the other; and were there not then made a counteracting inclination of the rudder, constituting what is called *weather-helm*, the ship's head would come round to the wind. Now ships so rarely have the wind exactly astern and the masts quite erect, that to diminish the almost constant necessity for *weather-helm*, the mast or masts, and consequently the mass of the sails, are placed nearer to the bow than to the stern.

Again, because the bow of a ship is oblique below as well as on the sides, the water, when she moves, is constantly tending to lift the bow; hence when a vessel is dragged by a low horizontal rope, as a boat is when attached to a sailing ship's stern, or is moved by paddle-wheels, like steam-boats, the bow rises more or less out of the water, and the stern sinks in the hollow or furrow of the track; but when a ship is driven by sails, which are high on the mast, and are acting therefore as by a long lever to depress the bow, the two opposing tendencies just balance each other, and the vessel sails evenly along.

380. It may be observed here that, while greater breadth of prow causes increased resistance to the advancing motion of a ship, greater length of hull has very little influence, for the prow opens the way for any length of hull, and there can arise only a little increase of friction from increase of length. The same principle explains why, in artillery practice, elongated shells or shot can be thrown much farther than globular masses of the same weight. In the small-bore rifles of the present day, as has been experimentally proved by Sir Joseph Whitworth, the length should be at least three times the diameter; and a like rule holds for ordnance projectiles. A 9-pounder Whitworth gun has been found to throw a projectile, four diameters long, to a distance of fully six miles. Such a range would to our ancestors have appeared as incredible as the labours of Hercules.

381. The *common windmill* furnishes another important illustration of oblique fluid action. The face of the windmill, as a whole, is turned directly to the wind, but the faces of the four flat vanes or sails, which appear as the arms of the great wheel, are individually oblique. Thus the edge, *a*, of the vane, *a e* (fig. 99), is more forward as regards the coming wind or a spectator in front, than the edge, *e*; and the action of the wind, therefore, being perpendicular to the oblique surface, *a c*, pushes it in a degree towards *a*, as the point of the arrow shows. The same remark applies to each of the other vanes, where the edges, *b*, *c*, and *d*, are in front, and those marked by the fainter lines are farther back; so that each vane produces an equal effect in turning

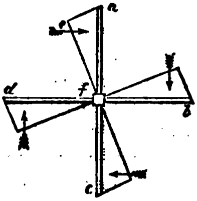

Fig. 99.

the wheel. By the "resolution of forces" (Arts. 129 and 130), we can tell in what proportions the force of the wind is exerted to push the wheel backwards against its supports, and to turn it round.

Windmills were first used in Europe in the fourteenth century, and they are still of great importance in countries where there are no waterfalls, and where fuel for steam-engines is expensive. In some of the richest Continental landscapes every height is crowned by its busy windmill, grinding corn, or sawing wood, or pressing oil-seeds ; and over the plains, similar wheels are pumping water for domestic use, or incessantly draining the land.

The *smoke-jack* of our chimneys is a small windmill, driven by the ascending current of air in the chimney.

The *feathering of an arrow* acts in part on the principle of the windmill. The feathery projection from the shaft is not quite straight, but winds round it a little, like the thread of a screw ; and the arrow, therefore, constantly turns as it flies, and goes straight to its object even if the shaft itself be somewhat bent, because any deviation is constantly correcting itself.

The rifling in fire-arms consists of spiral furrows or threads along the interior surface of the barrel, so that the bullet in passing out receives a turning motion round the line of its flight, corresponding to that of a feathered arrow, and produces similar results. A bullet which receives any other turning motion than round the line of its course—and most bullets from an unrifled barrel do acquire such, owing to some irregularity of their form, or to unequal friction at the mouth of the piece—is sure to deviate from its course, because unequally pressed or resisted by the atmosphere. The greater friction and pressure from which it turns away, is on that side of the ball which is advancing more quickly than the centre. A good rifle fixed to its place will send a succession of shots through the hole made in the target by the first shot.

382. It was supposed by some that a wheel which the wind turned by *direct* action on flat projections round the circumference, as water turns common water-wheels, would be more effective than the windmill-wheel above described, which is turned by *oblique* pressure on its face, and accordingly a wheel like a water-wheel, only with broader vanes, was constructed and placed so that only one side was exposed to the wind—but it was found to be a comparatively powerless machine. The wider expanse of the oblique-vaned face was found to be much more than a compensation for the obliquity of the wind's action upon it.

383. A windmill-wheel, made to turn during a calm by force applied to its axle, is, according to the law of action and reaction being equal and contrary, pressed endways with nearly the force used in turning it, owing to the reaction of the still air through which its oblique vanes are caused to sweep. If, in such an experiment, the windmill-wheel is supported on the mast of a floating boat, it urges the boat along with the force referred to.

Such a wheel placed in a short cylindrical tube or passage has been used to produce an artificial wind or air-current for the ventilation of closed spaces. A small wheel of the kind, carried in the hand of a person walking along in a calm, turns as if wind were blowing on it at the rate of the walker's motion, and if connected with a train of wheels and an index, like those of the common gas-meter, it indicates the length of space passed through. Such a wheel placed in the wind tells the speed of the wind. And such a wheel fixed on the end of a spindle and caused to spin round like a humming-top, rises into the air, constituting a kind of flying machine.

384. There are situations where it would be advantageous to use water-wheels constructed with arms and oblique surfaces like the common windmill wheel: namely, in streams deep enough to allow the whole wheel to be immersed. Because water is more than 800 times heavier than air, bulk for bulk, its force, either acting when itself in motion, or in resisting and re-acting against other motions, is proportionally great. This explains the marvellous efficacy of such a water-wheel when used on board ship, as now, under the name of screw-propeller, constituting the great instrument of steam-navigation.

385. The so-called *screw-propeller*, when first offered to notice, was far from being completely understood either by those who proposed it—several of whom had taken patents for it as a novelty—or by those opposed to it as being less effective than the paddle-wheel. The advocates for it first used a screw of several turns of the flange, whence its name was derived; but they soon found that two turns like the common cork-screw answered better than three or more; then that one turn was better than two; and, lastly, that half a turn, divided into two opposite arms, like two arms of a windmill, answered best of all. At first, few on either side seemed to be fully aware of the following facts:—

1. That this propeller differed from the paddle-wheel, almost exactly as the common broad-faced windmill with oblique surfaces

differs from the common wheel partially exposed to the wind, as described in Arts. 381, 382.

2. That the so-called mechanical power—the screw, does not at all waste force on account of the obliquity of the surfaces of contact, provided the external screw or nut is firm or unyielding.

3. That a fluid surface if pressed upon by a solid which passes as rapidly along or over it as the propeller-surface passes over the water-surface against which it bears, resists nearly as effectually as a solid surface would, and that the propeller, therefore, when the pitch of the flange is properly adjusted, loses less force by the yielding of the water than a paddle-wheel does.

This very important and little-considered fact, of the almost solid resistance of a fluid to a rapidly passing pressure, is seen in such cases as the following. A cannon ball always rebounds from the surface of water, almost as from the surface of a stone pavement, when it is shot in a nearly horizontal direction. The ball, when it descends and touches, is resisted by the inertia and reaction, not of its own bulk of water, but of perhaps a hundred times as much, within the one second or two of contact as it passes quickly along; and it therefore rebounds and relapses several times before its motion is exhausted. The like happens when a boy at play throws a flat pebble or oyster shell along the surface of a pond and sees it skip and leap forward. The same principle is illustrated by the long-resisted and slow descent of a broad leaf falling from a tree, when it zig-zags and thereby touches much air,—in the slow slanting motion of the boomerang descending,—in the mode of flight of the great albatross, whose wings appear scarcely to move as he glides about in the atmosphere supported by the resistance offered to the under surface of his expanded wings by the new air, which he every instant reaches.

The author, when he published this work, before the screw-propeller had been tried at sea, explained the true theory by reference to the windmill-wheel, &c., as here repeated; but not having had occasion to consider the matter closely, he did not then question the opinions which had been given by eminent practical men, that there would be loss of power in substituting the oblique, lateral, or twisting pressure of the screw for the direct backward pressure of the paddle-wheel. After a time, however, learning by accident that a friend of his who knew little of science, had been induced to lend a large sum of money to build a vessel of size sufficient to test completely the qualities of the screw, he was led to review the subject in detail, and he then saw the reasons here stated for approving of the project. There was opposition with unfavourable judgments from many high quarters—as there had been before in regard to novel inventions, such as gas-lighting, locomotive engines on railways, steam navigation on the high seas, the electric telegraph, penny postage, &c.—but gradually the opposition ceased. The vessel referred to was afterwards well known as the *Archimedes*, so named by the last patentee of the screw—who erroneously thought that the propeller resembled in principle the screw of Archimedes, described in Art. 389. This experiment drew the attention of Government, and of engineers generally, to the subject, and a new construction of mercantile vessels and war ships in all countries has been the momentous result.

386. The operation called *sculling*, (which is the propelling of a boat or vessel by the use of a single oar, resting on a round-headed prop or nail at the stern, and made to vibrate from side to side,) is referable to this law of oblique liquid impact. In all positions, the surface of the oar pressing the water is turned obliquely backwards; hence the re-action of the water drives the boat forward. In China, vessels of more than 100 tons are moved by a single large sculling oar, which half the ship's company may be urging at the same time. A sculling oar may be regarded as a single vane of such a propelling wheel or water-screw as above described, made to sweep across, behind the vessel, alternately to the right and to the left.

The action of a fish's tail, or of the bending of an eel or snake in water, partly resembles that of the sculling oar. Many people believe that the tail of the fish is only the rudder of the body, and that the fins give it forward motion—as is true of a bird's tail and wings; but the fish's tail is in fact its great instrument of motion, while the fins serve chiefly to steady and direct the motion.

Hydraulic Machines; Water-wheels and Pumps.

387. In the progress of civilization many different means have been devised for the raising of water from depths to supply the lack of natural provision of this liquid, which is to the world of animal and vegetable life what the blood is to the body.

The first improvement on the simple bucket attached to a rope, and pulled up by the hand, was the use of an axle and winch, to lessen the toil of lifting the bucket, and to enable larger buckets to be used.

A further improvement was to have a succession of buckets fixed on an endless rope, which passes over two wheels, so that the buckets dip in the water and are filled as they are carried round the lower wheel, and discharge their contents as they pass over the top wheel. This is an old contrivance, and is still in use, especially for the dredging of harbours.

A *bucket-machine* of this sort, called the *noria,* is common in the East for irrigation purposes, and in these the buckets consist of a series of earthen pots simply.

388. Instead of buckets on such an endless rope or chain, there may be a series of flat discs of wood or metal drawn up through a large tube or barrel, like loose-fitting pistons, and raising a copious stream. This is the contrivance called the *chain-pump,* which used to be the only pump in use on board our large line-of-battle ships.

More simple still is the use of a rough endless rope of hair; this, carried rapidly up through a pipe, will bring a considerable quantity of water with it, which will be thrown off by centrifugal force into a reservoir at the top, where it passes over the upper wheel.

389. An ancient contrivance, by means of which water may be readily raised in large quantity to a moderate elevation, is the *Archimedean screw.* It is represented in fig. 100, and consists of a pipe open at both ends, wound like a screw upon a sloping cylinder or shaft, and with its lower mouth dipping into the water. At each revolution of the barrel the lower turns of the pipe are filled with water, which, as the cylinder continues to turn, gradually rises to the top, as if drawn up an inclined plane. There are usually three threads of the screw, wound at an angle of about 60° to the axis of the shaft, which should not be inclined at a greater angle than from 30° to 45° to the horizontal.

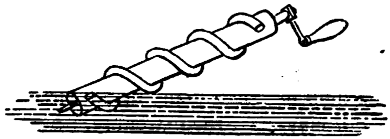

Fig. 100.

Archimedean screws are still much used in Holland for draining, and are commonly driven by windmills. They are a simple and economical means of raising water in large quantity to a moderate height, such as fifteen or twenty feet. In France they are sometimes made of five or six feet diameter, and turned by steam power.

390. The *Persian wheel* is the name given to a simple wheel, by which the streams in Persia are frequently caused, by their own action, to lift a part of their water into elevated reservoirs, from which it again flows in sloping channels to fertilise the fields and gardens. A large water-wheel may be placed so that the stream shall turn it, while buckets around its circumference are filled as they sweep along below, and are emptied into a reservoir as they pass above—or instead of buckets, the spokes of the wheel may themselves be made hollow, and curved as in fig. 101, so that their extremities may dip into the water below and receive a quantity of it, to run along them as they rise, and be discharged into a reservoir at the centre.

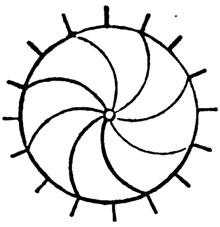

Fig. 101.

391. Of modern water-raising engines the most common and important are the *lifting* and *force pumps*. These, being dependent upon atmospheric pressure, will be described in the following section. The only other machine we need here describe coming under the present head, is the self-acting contrivance now in common use, and known as the

Hydraulic Ram. It has been often observed that while water is running through a long pipe, if a cock at the extremity be suddenly shut, a smart shock is produced there. The reason is, that the momentum or shock-giving power of a moving liquid is the same as that of a solid of the same weight moving at the same rate. Then, as a fluid presses equally in all directions, a leaden pipe of great length may, near the extremity, be widened, or even burst in this experiment. The employment of this forward pressure of an arrested stream for raising water was first suggested by Montgolfier in the end of last century; and the arrangement of parts contrived to render it available has been called, on account of the shock produced, the *hydraulic* or *water-ram.* The ram (fig. 102) may be described as a sloping pipe in which a stream flows, having a valve at its lower end which the action of the stream is made to shut at intervals and so arrest itself automatically; a small tube rising from near that end towards a reservoir above, to receive a portion of the water forced up at each interruption. The water allowed to run for a certain time, in a pipe ten yards long, two inches wide, and sloping six feet, acquires momentum enough to shut the valve, *a*, and force about half a pint of itself into the air-vessel of a tube leading to a reservoir forty feet high. The stop-valve, *a*, is made so heavy, that the stream must run for a certain time to acquire force enough to shut it; and in the instant of its shutting, a portion of the advancing water passes upwards through the other valve, *b*, towards the high reservoir. The water in the main pipe, then becoming stagnant, no longer has power, by its weight alone, to keep the valve, *a*, shut; this, therefore, falls open and the stream begins again, to be arrested after a time as before; and as long as the supply of water lasts, the action of the apparatus continues. The action of a water-ram has been compared to the beating of an animal's pulse. The upright tube has usually at the bottom an air-vessel or *air-matrass*, *b*, which, by the elasticity of the confined air, converts the interrupted gush first received, into a nearly uniform current towards the reservoir. The supply of air to this vessel requires to be renewed from time to time by the contrivance called a *shifting-valve*, as part of the confined air is continually passing away with the water through the ascension pipe.

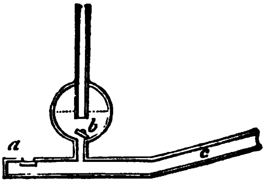

Fig. 102.

392. *Water-pressure engines* may be called the reverse of the hydraulic machines we have just mentioned. In these we have water standing at a height made, by its mere weight, to act as a source of motive power. One of the simplest of these is what is called

Barker's Mill.—This consists of an upright tube, *a b* (fig. 103), with a funnel at the top, into which water pours from a reservoir. The water fills the tube, *a b*, and its two arms, *b c* and *b d*, in each of which, near the end, there is an opening from which the water spouts, and by its re-action, or the unbalanced pressure on the interior of the tube opposite to the opening, pushes the arm in the contrary direction. Then as the two holes are on opposite sides of the arms, both co-operate to whirl the axis round, and thereby to turn a millstone above, or to do any other work.

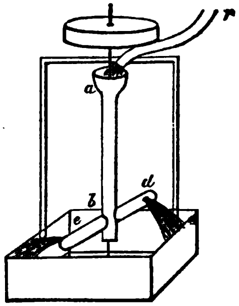

Fig. 103.

393. The *Turbine wheel* resembles Barker's mill in principle, although differing in form. It has below, instead of the two arms with spouting apertures, a cylindrical drum, *e f* (fig. 104), close at top and bottom, divided into a number of curved channels as outlets for the descending water, all pointing in the same way, as shown in the sectional view, *g*. The reaction of the water as it glances off the curved blades turns the cylinder. This arrangement is equally efficient for large or small falls of water, and has the advantage of being extremely simple, requiring no valves nor internal parts, but only curved vanes or walls of division. They are extensively used as a source of motive power for mills or any kind of machinery, and are exceedingly economical where a plentiful supply of water is available, seeing that they may be made of almost any power.

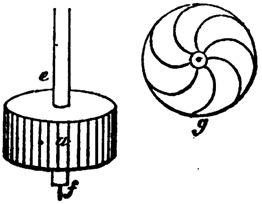

Fig. 104.

394. *Appold's centrifugal pump* is a contrivance which may be called the reverse of the turbine wheel. It is simply a turbine placed with its axis horizontal, and having an opening round the axle by means of which the water is admitted to the curved vanes. On being rapidly whirled, the water is, by centrifugal force, moved towards the circumference of the wheel, and may thus be forced up a vertical tube with great efficacy if the height be moderate.

SECTION III.—PNEUMATICS, OR THE LAWS OF GASEOUS PRESSURE.

ANALYSIS OF THE SECTION.

In gases, of which air is taken as the type, the particles are mutually repellent, and tend to occupy an indefinitely large space, if unconfined; this property, together with extreme lightness *and* compressibility, *explains the difference between liquids and gases. Yet the agreements between the two classes of fluids are more numerous than might at first sight appear: among the chief of these are,* equal transmission of pressure in all directions, *and* downward pressure through gravity or weight. *The latter was first exhibited by the invention of the* Torricellian Tube, *or the* BAROMETER, *one of the most interesting and important inventions in science, on account of its many practical applications, such as indicating proximate* weather-changes, *the* heights of mountains, *&c. Many otherwise mysterious phenomena find a simple explanation in the pressure of the atmosphere; the actions of the* sucking-pump *and of the* syphon *are illustrations. The air, like the more palpable liquids, buoys up bodies immersed in it with a force equal to the weight of fluid which they displace, and such bodies will float or sink according as this weight is greater or less than their own weight; on this is based the theory of* ballooning, *of* ventilation, *of* winds, *&c.; a lighter gas will thus be buoyed up by a heavier one, as oil or spirits float on water. But the nature of gases, as explained by the modern* kinetic *doctrine, does not allow the permanent separation of them by gravity; for a mutual interpenetration or* diffusion *invariably takes place, with a rapidity depending on their relative densities.*

395. Pneumatics has for its subject, as explained in the beginning of Section I. (*Hydrostatics*), the properties of that class of fluids called gases, which are distinguished from liquids by their great rarity or lightness, and by their extreme compressibility and elasticity. The term is derived from a Greek word, *Pneuma* (πνευμα), signifying *air* or *breath*, because common air is the most accessible for study, and is representative of gaseous substances generally; just as the term hydrostatics comes from the Greek word ὕδωρ, meaning *water*, that being the most common, and the type, of all liquids. Gases, like liquids and solids, differ in their special or *chemical* qualities, but these do not interfere with the *mechanical* conditions common to them all. The laws of "equal pressure in all directions," of "pressure varying with the depth," of "liquid level," &c., may be proved experimentally with the most convenient liquid, water, but they are found to be equally true of all other liquids. So the laws which hold in the case of common air will be equally binding in the case of all other gases under similar external circumstances.

396. While the ancients had that vague notion of air, which made them apply to it almost indifferently the names of *air*, *ether*, *spirit*, *breath*, *life*, they never dreamt of making experiments upon it, with a view to prove its identity with grosser matter. And one of the most interesting parts of the history of man's progress in knowledge, is that which tells how the light gradually dawned upon this subject. Galileo was the first to conclude that air made a definite pressure upon things at the surface of the earth—as in forcing water into the exhausted barrel of a common pump; Torricelli and Pascal proved that this was caused by its weight, and even attempted to estimate the height of the aërial ocean; Priestley, Black, Lavoisier, and others discovered that air or gas was of different kinds—that, for instance, one kind, called oxygen, could unite with a metal, so as to increase its bulk and weight, and to produce a compound of totally new qualities; and they at last analysed the atmosphere itself, and exhibited it as a mixture of two distinct substances. The nature of gases has now been so thoroughly investigated, that they can be measured, manufactured, and operated upon just as readily as the more palpable liquids and solids.

397. The suspicion being once excited, that air is as much a material fluid as water, only much less dense by reason of a greater separation and repulsion of the particles, it is easy to confirm the analogy by reference to familiar facts. Thus,—as a leathern bag when opened out under the surface of water becomes full, and, if its mouth be then tied, cannot afterwards be pressed together: so a bladder, opened out in air and then closed, remains bulky and resisting, and forms what is called an air-pillow. The motion of a flat board is resisted in water: the motion of a fan is resisted in air. Masses of wood, sand, and pebbles, are rolled along or floated by currents of water: chaff, feathers, and even rooted trees, are swept away by currents of air. There are mills driven by water; and so there are mills driven by the wind. Oil set free under the surface of water, or placed there in a bladder, is buoyed up to the surface:

hot air or hydrogen gas placed in a balloon, is buoyed up in the air. A fish moves itself by its fins and tail in water: a bird moves and directs itself by its wings and tail in the air,—and as on emptying the water from a vessel in which a fish swims, the creature falls to the bottom, gasps a few moments, and dies; so, on exhausting the air from a vessel in which birds or butterflies are enclosed, their flapping wings are powerless to support them, and if the experiment be continued, they soon die.

Lightness of Air.

398. Air, as it exists near the general surface of the earth, is so light that a cubic foot of it weighs only about an ounce and a quarter. The same bulk of water weighs nearly a thousand ounces; in other words, water is above eight hundred times heavier than air. Other gases have their different specific gravities, just as liquids or solids have. Thus steam—that is water in the form of gas or vapour—is little more than half as heavy as the same bulk of air: hydrogen is only one-fourteenth as heavy, and carbonic acid gas, which gives the effervescence to soda-water, brisk ale, and champagne, is so much heavier than air, that it may be poured out of one open vessel into another, almost as a liquid may be, or, more exactly, as water might be poured upon oil.

Elasticity of Air.

399. A small bladder or india-rubber balloon full of air may be squeezed between the hands so as to be much reduced in size, but on being relieved from the pressure it immediately regains its former bulk.

If a glass or metal tube, *a b*, of uniform bore (fig. 105), be fitted with a moveable air-tight plug or piston, *c*, the air between the piston and the close bottom *b*, may be compressed to a very small part of its usual bulk; but when allowed, will push the piston back again with the same force as it opposed to the condensation, and will recover the volume which it had before the experiment.

Again, if the plug were at first only an inch from the bottom, enclosing air of the usual density, then on drawing it up to the top, the inch of air beneath it would expand so as to occupy the whole tube of say six inches length, and would have, of course, only a sixth of its original density.

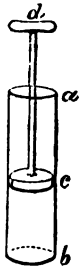

Fig. 105.

The tube with its piston just described becomes, according to the position of valves, either a forcing syringe for injecting and condensing air in a vessel, or what is called a sucking pump for exhausting or removing air from a vessel; both operations depending on the elasticity of the air.

400. That useful contrivance, *a valve*, for whatever purpose used, is in principle merely a moveable flap, or little door, *a* (fig. 106), hinged over an opening, *b*, which it is made to close by its weight, or other gentle force. Such a flap, it is evident, will allow fluid to pass only in one direction, *viz.* outwards from the opening, for any fluid tending inwards must shut the flap. The flap of a common bellows is a familiar example.

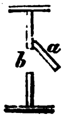

Fig. 106.

401. A barrel and piston is a *condensing syringe*, when, in a passage of communication between the bottom of the syringe and a receiving vessel, there is a flap or valve allowing air to pass *towards the receiver but not to return.* The piston, therefore, at each stroke forces what the barrel contains of air into the receiver. When the piston is lifted again after the stroke, air re-enters the barrel from the atmosphere, either through a valve in the piston itself, or through a small hole near the top of the barrel. A second, and each succeeding downward stroke sends a like measure of air into the receiver, until the desired quantity is accumulated.

"*The Air-pump.*"

402. To convert a forcing into an exhausting syringe or pump, commonly called an *air-pump*, it is necessary only to reverse the position of the valves; then, on the descent of the piston, all the air between it and the bottom of the barrel, instead of entering the vessel or receiver, as in the last case, escapes by a valve in the piston itself towards the atmosphere. On the raising of the piston, a perfect vacuum would be left under it, but that the valve below, in the passage from the receiver, being then opened by the elasticity of the air in the receiver, allows a part of that air to follow the piston. Thus, at each stroke, a quantity of the air, proportioned to the size of the barrel, is removed from the receiver.

In the ordinary air-pump there are usually two cylinders or barrels, in which tightly-fitting pistons are worked by the pinion and rack arrangement shown in fig. 107. The double barrel construction not only quickens the rate of exhaustion, but has the farther advantage that the atmospheric pressure, of fifteen pounds per square inch on the upper surface of either piston, and which for a single piston would have to be overcome by the worker in lifting it, is here balanced always by the same pressure on the other piston. Both barrels communicate with the upright tube, to which the flat smoothly-ground plate, P, is screwed air-tight.

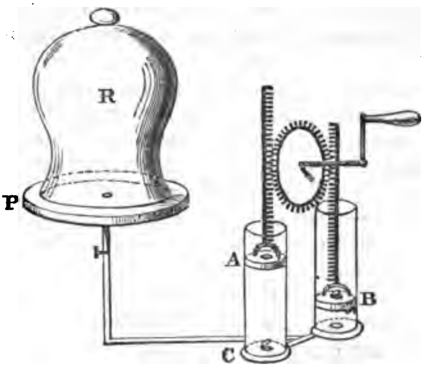

Fig. 107.

The glass bell, or *receiver*, R, with a smooth-ground lip, being placed on this plate, forms an air-tight enclosure, from which we can exhaust the air. It will be understood from the figure, (in which to avoid confusion the framework is not shown,) that while the piston, A, is being raised and B is depressed, the valve in A is closed, while that at the bottom of its cylinder, is opened by the elastic force of the air in the receiver. The positions of the valves in the other cylinder, B, are just the reverse of these, so that the air is prevented from returning to the receiver, and is expelled through the valve in the piston, B. Thus, the air within R gradually gets rarer and rarer, till at last a more or less perfect *vacuum* (or empty space) is obtained, and we have the means of exhibiting the many interesting phenomena that we now come to review.*

403. The law of elasticity of air or any gas is, that its outward spring, or resistance to compression, increases exactly with its density, or the quantity of it collected in a given space.

It has been ascertained, by experiments to be described presently, that in the atmospheric ocean surrounding the earth there are nearly fifteen pounds of air above every square inch of the surface of the earth. It is found, also, that air is reduced to half its bulk, or becomes of double its ordinary density, by an additional pressure of fifteen pounds on the square inch; to one third of its bulk, or of triple density, by triple pressure, and so forth. On the other hand, it dilates to double bulk if the pressure be diminished to half, and to any greater bulk, even beyond a thousand-fold, if the pressure be diminished in the corresponding degree.

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* Other means of effecting the same purpose will be described at the end of this section.

This fundamental law is of great importance, as it holds good for all aëriform fluids as well as common air, and it throws light, therefore, on the action of steam-engines, air-guns, and pneumatic machines generally. It also explains the condition of our atmosphere as to density at various elevations; informing us, for instance, that when a balloon has risen through half of the atmospherical mass, the air around, as well as the gas enclosed, is of only half its density at the surface of the earth; and therefore, that if it be only half full when leaving the earth, it becomes quite full at such an elevation.

We know not if there be a limit to the rarefaction of air on the removal of pressure. We cannot say at what distance the weight of the particles may just balance their mutual repulsion; and therefore we cannot accurately assign the height of our atmosphere; but we know that the expansion of air is exceedingly great, from the fact that the portion left in the receiver of an air-pump has still spring or elasticity enough to lift the valve of the pump, when less than the thousandth part of the original quantity. The air left in the receiver of the most perfect air-pump after complete exhaustion is considered to have the 12,000th part of the density of that upon the surface of the earth.

404. Air is what chemists call a permanently elastic gaseous body, for no degree of pressure or intensity of cold combined, has sufficed to bring it into a liquid state. Mr. Perkins subjected it to a pressure of 800 atmospheres, or 12,000 pounds on the square inch (Art. 414), but it still remained gaseous. The late Prof. Faraday submitted oxygen, one of the important constituents of air, to a pressure of 877 pounds on the square inch, and at the same time cooled it, by a mixture of solid carbonic acid and ether, to 172° below the freezing point of water, but it still remained a gas. On a more recent occasion Dr. Andrews, of Belfast, subjected air to a cold of 220° below zero, and reduced it by pressure to the 1-675th of its volume, in which state its density was little inferior to that of water, but in spite of this pressure and cold, it retained its gaseous condition.

The degree to which air may be condensed is always directly as the pressure, until the containing vessel gives way. Thus, with a pressure of 800 atmospheres, 800 cubic inches are made to occupy the space of one cubic inch, and on the removal of the pressure there is an immediate expansion to the original bulk. In

Dr. Andrews's experiments above mentioned, 675 cubic inches of air were condensed into one, but this did not alter its physical condition as a gas. It was not liquefied.

405. The elasticity of air is illustrated by placing within the receiver of an air-pump a bladder, or caoutchouc balloon, having a very little air left in it, and its mouth firmly tied. On withdrawing the air from the receiver, we see the bladder slowly swell, with force sufficient to lift a considerable weight laid upon it, or even to make it burst.

Shrivelled apples or other fruit, treated in the same way, become for the time quite plump and fresh-looking.

A miniature figure of a man, made in india-rubber, may appear lean and lanky before the air is exhausted from the receiver, but swells up in an amusing manner after a few strokes have been given to the air-pump.

If a glass bulb with a long stem be almost filled with water and inverted in a glass of water, and the whole placed under a receiver, as the exhaustion goes on, the air-bubble left in the bulb will expand, so as to force all the air and water out of the bulb and tube. When the receiver is re-filled with air, the water will be forced back again till the air in the bulb is reduced to its original bulk.

Very similar to this is the interesting experiment with an egg. In the wide end of an egg there is always a small bubble or portion of air. If a hole be pricked in the narrow end of the egg, and it be placed in a wine-glass under a receiver, the expansion of the bubble at the upper end, when the receiver is exhausted, will expel the contents into the wine glass ; while the readmission of the air into the receiver will as curiously replace the whole within the shell.

Another lecture-room experiment of the same description consists in taking two bottles, one of which is nearly filled with coloured water ; a bent glass tube passes air-tight through a cork in the neck of the one, its two legs reaching nearly to the bottoms of the two bottles. When the whole is under a receiver and exhaustion takes place, the expansion of the air left in the one expels its liquid contents, and the water is transferred to the other. When we re-admit the air, the liquid is replaced in the first bottle.

In all these instances the explanation is simply, that air (or any gas) tends to expand without limit when all confining pressure is removed ; and it expands to occupy more space just in proportion as that pressure is lessened.

The curious instrument called the *air-gun* is a gun having a strong globular vessel of copper attached under the lock, into which air is injected by a forcing syringe to be thirty or forty times as dense as the atmosphere around. Hence the elasticity, or pressure tending outwards, is thirty or forty times fifteen pounds on the square inch, and when the confining valve is opened for an instant by the action of the lock, a portion of the air rushes into the barrel, and propels the charge with the force stated. The effect of air thus condensed nearly equals that of gunpowder, and one charge of the globe suffices for many shots; the force becoming less, however, after every successive discharge.

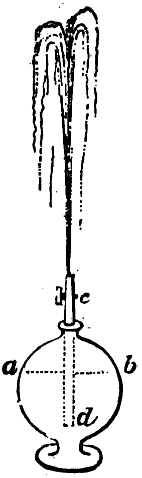

Fig. 108.

406. If a stout bottle or vessel, *a b* (fig. 108), partly filled with water, have a tube, *c d*, passed air-tight through its neck to near the bottom of the water; and if more air be now forced through this tube, so as to accumulate in the upper part of the vessel above the water surface, *a b*; then on turning the cock *c*, the elasticity of the condensed air will press the water out as a beautiful jet, to a height proportioned to the condensation. Or if such a vessel, with air of common density, be placed under a tall receiver, on working the pump so as to diminish the pressure of the air in the receiver, a jet of water will be projected by the elastic force of the confined air. In one form of table-lamp, the oil is supplied from a reservoir far below the wick by the force of condensed air.

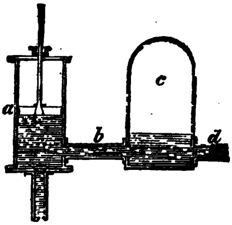

Fig. 109.

407. The elasticity of air is rendered very serviceable in connection with water-pumps, such as are used for fire-engines or for watering gardens. A pump throws its water not continuously, but by a distinct gush at each stroke. Now the desired uniformity of current is attained by causing the gushes from the pump, *a* (fig. 109), to enter by the passage, *b*, into a large vessel, *c*, of which the upper part is full of condensed air, and from the other side of which, at *d*, the water issues on its way. The air in the vessel, *c* (called the *air-chamber*), is then condensed by each gush of the entering water; and its resisting spring or elasticity, continuing to act during the interval of the strokes, forces the water along the pipe, *d*, at a practically uniform rate. Such a pump is itself made to take in a little air at each stroke, so that not only is the air-vessel always supplied, but some air is constantly passing on with the water, and effecting the highly useful purpose of giving an elasticity to the whole contents of the pipe and its ramifications. In the common *fire-engine*, there are generally several water-pumps working together, which throw their gushes into the air-vessel, from whence it passes in a nearly uniform jet to the point desired.

408. The condensation and resulting spring of air are remarkably exhibited in the *Diving-bell*, which enables men to descend into the depths of the ocean and recover sunken treasures, or to lay the foundations of lighthouses, breakwaters, and harbour walls, just as securely as they found edifices on the dry surface of the earth.

The diving-bell is a heavy, open-mouthed vessel, large enough to hold one or more persons. It is lowered, mouth downwards, into the water from a projecting support either on land or on the deck of a vessel. On first entering the water it appears full of air; but as the pressure of water around the descending bell increases with the depth, the volume of the contained air gradually diminishes, and at thirty-four feet is reduced to one-half. The bell then, unless more air were supplied, would of course be half full of water, and a person within it would, at each inspiration, receive twice as much air into the lungs as when breathing above the surface. A constant supply of fresh air is sent down to the bell by a forcing-pump; and the heated and contaminated air, which has served for respiration, and which rises to the top of the bell, may be allowed to escape by a tube descending on the outside. The men who work at a distance from the bell have tubes of communication with it, by which they inhale the air required; while the respired air is allowed to pass into the water above them. A man cannot breathe easily by such a tube if he be either above or below the level of the water in the bell; for if above, the air in the bell is more compressed than in his chest, and is forced towards him, so as to require an effort to resist its admission; and if below, his chest is bearing greater pressure than the air in the bell, and he must therefore act strongly with the muscles of the ribs to draw the air down to him.

A simple illustration of this is to immerse two bladders of air connected by a long tube, to unequal depths in water; the air is forced from the lower one into the upper, because the lower one is more compressed. The difficulty of pumping air down to the diving-bell increases, of course, with the depth to which it has descended. An engine, or force-pump, employed to inject air into the bell, must act with a force of over fifteen pounds per square inch for every thirty-four feet to which the diving-bell is lowered, because this is the force with which the water presses on the air within the bell.

Instead of the large diving-bell formerly employed, it is now found preferable in most cases to have merely a waterproof dress for the person, connected with a small bell or helmet covering the head and face, which is kept supplied with fresh air by a forcing-pump working constantly above the water-surface. The diver, with this dress, can move about much more freely than when in connection with the large bell, for, under these circumstances, he is not limited to one level.

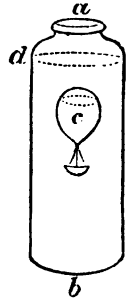

Fig. 110.

409. The action of the philosophical toy, called the *Cartesian diver*, depends chiefly on the elasticity of air; and illustrates most of the laws of fluidity. It is a light glass balloon, *c* (fig. 110), with a small opening at the bottom, and a little car or basket hanging to it. While the globe contains air only, it would float with half the globe above the surface; but by introducing water, the specific gravity of the whole may be adjusted so that it shall float with only a small portion above the water-surface. If it be then placed in a tall jar of water, *a b*, the mouth of which is covered by bladder-skin or india-rubber tied air-tight upon it, on pressing such covering with the hand, the balloon will immediately descend in the water; it will rise again when the pressure ceases, and will float about, rising, or falling, or standing still, according to the pressure made. The explanation of this is, that pressure made on the top of the jar first condenses the air between the cover and the water surface; this condensation then presses upon the water surface below, and by influencing the water through its whole extent, forces as much more water into the globe as to render the balloon heavier than water, and therefore heavy enough to sink. The air within the globe being thus compressed, repels, as soon as the pressure ceases, the lately entered water, and the balloon becoming, as before, lighter than water, ascends to the top. If the balloon be adjusted to have a specific gravity too nearly that of water, it will not rise of itself after once reaching the bottom, because the pressure of water then above it will alone produce the condensation of the air required to make it descend.

The water required to make the apparatus just float, may be introduced by heating the bulb and suddenly immersing it in cold water.

410. The famous fountain of Hero, by which water is made to spout far above its source, depends upon the elasticity of compressed air. The vessel, *d* (fig. 111), is first filled with water, while *b* and *a* contain only air. On pouring water into *a*, the water of *d* darts upwards through the jet-pipe, *e*, to a height proportioned to the height of *a* above *b*. The reason is, that the water from *a* descends by the tube to *b*, and compresses the air in *c*; which compression conveyed along the other tube from *c* to *d*, acts on the water in the vessel, *d*, and causes it to jet upwards. As the pressure is produced by the column of water, *a b*, the jet is proportioned to the length of that column. This kind of fountain may have its parts concealed under a variety of forms, as exemplified in the second figure (fig. 112), and may thus become a pleasing ornament among flowers in a drawing-room or on a dining-table. It may be made of a size to play for an hour or more, and it will always recommence on the water being shifted from the low to the high reservoir. The water which jets from the vessel, *d*, when caused to fall into the vessel, *a*, feeds the compressing column, *a b*. A useful table-lamp, appearing a simple column, has been constructed on the principle of a Hero's fountain.

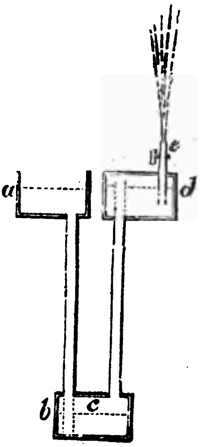

Fig. 111.

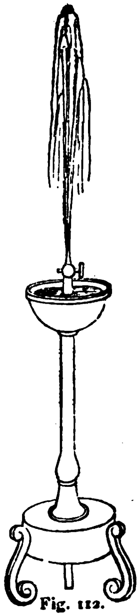

Fig. 112.

‘ *Pressure conveyed equally in all directions."*

411. A quantity of air or gas shut up in any vessel and compressed, is equally affected throughout; its tendency to escape from the pressure is equal in all directions, as is proved by the force necessary to keep similar valves closed wherever placed.

The pressure in one direction must be balanced by an equal pressure in the opposite, in order that a gas may remain in quiescence, otherwise there will always be a rush from where there is more pressure to where there is less. The actions of the common fire-bellows, and of the animal chest in breathing, blowing, sucking, &c., furnish instances of this kind.

The suddenness with which pressure on one part of a confined gas is communicated through the whole, is strikingly seen in the simultaneous outburst of all the gas-lights over an extensive building, or even in a long street, at any instant when the force supplying the gas is augmented.

Before proceeding farther, it may be as well to give an idea of

"*The modern or kinetic explanation of gaseous pressure.*"

412. The elasticity, pressure, outward spring, or tendency to indefinite expansion, which is the fundamental quality of a gas, is a consequence of an incessant commotion among its particles. We must picture to our minds the molecules of a gas as moving in all directions, constantly impinging against each other, and thus producing pressure on the sides of an enclosing vessel.

In a subsequent part of this section, under the head of *Diffusion*, we shall refer more specially to the facts on which this theory is based. At present we shall merely give a general idea of this *kinetic* theory of gases.

If the least quantity of any gas be introduced into a vessel, it will rapidly permeate the whole space enclosed. A little of the vapour of a perfume very soon fills the whole of a room, and makes its presence known to the olfactory organs. If any two gases, such as hydrogen and chlorine, the latter of which is thirty-six times as heavy as the former, be put into the same bottle or jar, they will be found after a short time to have each completely permeated the containing space, just as if the other had not been present at all.

The violence with which the gaseous molecules will beat against the confining walls will be greater, the less the space through which they are allowed to fly. For, if we assume that the elasticity of the particles is perfect, and that their actual velocity therefore remains unaltered by any alteration of the volume of the gas, the number of their impacts against the envelope will obviously be multiplied exactly as this volume is reduced. In other words, the intensity of the molecular impact will increase exactly as the volume diminishes, so long as the temperature remains the same. We have thus a simple explanation of the fundamental law of gaseous pressure, which is known as *Boyle's* or *Mariotte's law*, viz. :—

The pressure of any quantity of gas increases or decreases at exactly the same rate as its volume decreases or increases,

the temperature of the gas being supposed to remain unaltered. This might be readily verified by the following experiment :— Fit into a glass tube, A B (fig. 113), one square-inch in section, an air-tight piston sliding smoothly, and carrying a scale pan on the upper end of its rod, so that it may be pressed with known weights. Let us suppose that the piston and its rod and pan, P, are without weight, and let us consider the quantity of air, A B, in closed between the plug and the end of the tube. This quantity of air is confined within this space by the pressure of the external air, which, by experiments to be described a few pages hence, is about 15lbs. on the square inch ; and but for this pressure it would expand indefinitely. We find then that, if an additional pressure of 15lbs is applied to the confined air, the piston sinks from A to C, half down, that is, to the bottom ; and if other 15lbs. be laid on P, the piston will farther sink to D, such that D B is one-third of A B, and so on ; thus the space within which the air is confined is inversely as the confining pressure.

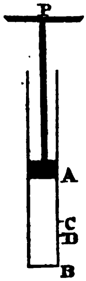

Fig. 113.

413. In perfect accordance with this kinetic doctrine of gases is the modern or vibratory theory of heat. When a bladder, partially filled with air, and closed at the neck, is put near the fire, the confined air swells up till the bladder becomes quite tight, or even bursts. The heating of the enclosed air is but the increasing of the energy of the molecular agitation within, which, in opposition to a constant and equal resistance (viz. the pressure of the atmosphere without), will manifest itself as an expansion of the enclosed air.

It is found that the rate of expansion bears a definite and uniform relation to the rise of temperature in the gas. This is known as the *law of Charles*, and is as follows :—

Air or any other gaseous fluid expands, against the pressure of the atmosphere or any constant pressure, by about the 1-491*st part of its* *volume for every additional rise of temperature through* 1°*F.; so that, by raising the temperature from the freezing to the boiling point of water, its volume would be increased by nearly one-third; or three cubic inches of air would swell up to occupy a little over four cubic inches.*

" The pressure or weight of the Atmosphere."

414. If a piece of bladder-skin or a pane of glass be lying at the bottom of a cistern holding water, the bladder or the glass exhibits no sign of being pressed upon, although it bears on its upper side the whole weight of the water directly above it; the reason being, that the water beneath the bladder resists just as strongly as the water above it presses. But if the bladder be tied closely over the mouth of a glass filled with water, and placed at the bottom of the cistern, and if, by means of a syringe or pump, the water can be extracted from within the glass, the bladder itself has to bear the whole pressure of the water above it, and will be torn or burst. Now this experiment may be closely copied in relation to our atmosphere or sea of air. If an open glass have its mouth covered over with bladder, no external pressure will be apparent, because there is a resistance of the air within, just equal to the pressure of the air on the outside:—but if air be then extracted from under the covering by means of an air-pump, the bladder is seen sinking down from the weight of the air over it, and at last bursting inwards with a loud report. By placing a circular piece of wood under the bladder-skin, for it to rest on, and a steel spring of known force to support the wood, we might ascertain very nearly the weight and pressure of the air over it. This mode, however, of ascertaining the weight of the atmosphere, is not that commonly used, but is described here as a readily conceived illustration of the present subject. The estimate is made much more elegantly and completely by means of the barometer, to be described farther on.

The pressure of the atmosphere is well exhibited by placing the hand on the mouth of a glass so as to cover it closely, and then extracting the air from the vessel: the weight of the atmosphere holds the hand down upon the mouth of the glass with a force which soon becomes painful. The pressure may be rendered visible by the following simple experiment:—Fill a short wide jar with carbonic acid gas and pour in enough water to cover the bottom from half an inch to an inch. Add quickly and without agitation, one or two sticks of caustic potash, and immediately cover the mouth of the jar with a thin sheet of india-rubber. This should be firmly tied round the neck of the jar. Now agitate the vessel. As the potash is dissolved, the carbonic acid is removed, and a vacuum is thus produced in the vessel. The pressure of the atmosphere forces the india-rubber downwards into the jar, converting it into a deep cup, and sometimes causing it to burst. The most perfect vacuum may be produced by filling a space with pure carbonic acid gas, and subsequently removing this gas by potash.

As should follow, from the pressure of fifteen pounds per inch at the surface of the earth being due altogether to the weight of the superincumbent atmosphere, we find that when a person rises from the earth, as in ascending a hill, and leaves part of the atmosphere beneath him, the pressure diminishes.

After the explanation of fluid pressure given under hydrostatics, namely, as acting equally in all directions, it is almost superfluous to remark, that the downward weight of the atmosphere is such a pressure. The bladder-skin which closes the mouth of the vessel described above, is as readily burst if turned sideways as if held directly upwards. Every body or substance, therefore, on the surface of the earth, dead or living, solid or fluid, is compressed with this force. In general, the pressure on one side of a body is just balanced by the equal pressure on the other, so that no sensible effect follows; and it is on this account that people remained so long in ignorance of the fact.

"*Atmospheric pressure on solids.*"

415. Because the atmospheric pressure acts equally on the whole surface of any body immersed in the air, if that pressure be in any way prevented from acting on one side, while it continues to act on the other, the one-sided pressure becomes immediately manifest. This is simply but strikingly illustrated by pressing two good bottle-corks together, end to end, so as to expel the air from between them, and tying over the joining a short piece of caoutchouc tube. If one cork be then seized and raised, the other cork will accompany it, as if strongly glued to it, and, if the touching surface has an area of an inch square, will lift a weight of fifteen pounds attached below. Broader barrel-corks so connected may lift more than fifty pounds. The explanation is, that the upper cork keeps off the atmospheric pressure from the upper surface of the lower cork, while that pressure (of fifteen pounds per square inch) continues on the under surface, supporting that cork and the appended weight. The same result is produced if, instead of using the caoutchouc tube to exclude the air, a length of glass tube be taken, into which the two corks, oiled to lessen friction, are introduced like two pistons in the barrel of a syringe.

For a like reason, to draw the piston of any good syringe away from the end of its barrel, while no air is allowed to enter between them, requires a force of fifteen pounds to each square inch of the surface of piston. If the syringe be suspended in the exhausted receiver of an air-pump, the piston will fall away by its own weight, and will be pushed back again, immediately on readmitting the air.

An air-pump receiver of about five inches diameter has at least twenty square inches of surface in its upper part or roof, and bears, consequently, a weight or pressure of atmosphere of twenty times fifteen, or three hundred pounds. While it has air within it, this pressure is exactly counterbalanced, and is not sensible ; but when exhausted on the plate of the air-pump, it is pressed against the plate with this force. As this pressure is in all directions, the pump plate is equally pressed upwards against the receiver, so that the heavy pump itself might be lifted by lifting the receiver. The sides of the receiver are also pressed towards each other, which is the reason why air-pump receivers must be made strong and of the arch or dome shape to withstand the great pressure. A flat piece of glass laid upon the open mouth of a receiver, so as to form an air-tight cover to it, is broken instantly by exhausting the air beneath ; and a bottle or receiver with *flat sides*, if exhausted, yields in the same manner. (See Art. 291.)

416. Illustrative of this pressure on solids, is the class-experiment of the *Magdeburg Hemispheres*, as they are called. Two hollow half globes of metal, *a* and *b* (fig. 114), are fitted to each other, so that their lips when touching may be air-tight. While there is air between them, balancing the pressure of the outward air, they can be readily separated from each other : but when the air is extracted from within by the air-pump, a force is required to separate them of as many times fifteen pounds as there are square inches in the area of the mouth. The air is extracted by unscrewing one of the handles at *b*, and then connecting the remaining stalk (which is hollow, and has a stop-cock), with the air-pump. This was one of the first experiments which drew popular attention to the substantial nature and properties of the air ; and it astonished the world. Otto Guericke, Burgomaster of Magdeburg, the inventor, had hemispheres made three feet in diameter, and when he exhausted them, on the occasion of a public exhibition, it is said that twenty coach

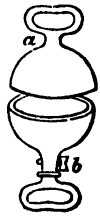

Fig. 114.

horses of the Emperor were unable to pull them asunder! There being no air pump when Guericke began his experiments (although he himself invented one afterwards), he dislodged the air from within the balls by first filling them with water, and then extracting the water by a common pump or syringe.

417. A boy, with his leather sucker, exemplifies the pressure of the atmosphere. He presses a circular piece of wet leather, as *a* (fig. 115), against a flat-faced stone, as *b*, and then lifts the stone by pulling a cord, *c*, attached to the centre of the leather. If the leather be so close in its texture that air cannot pass through it, and stiff enough not to be puckered and drawn together too much, a heavy stone may be lifted by it. In the important business of repairing or rectifying street pavements, not a little time and labour might be saved by adding a suitable tractor to the ordinary pickaxes and crowbars employed, seeing that it is often with difficulty that these are forced in between and under the stones.

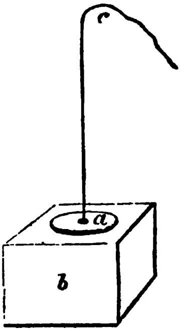

Fig. 115.

It is from having feet that act on the principle of the *sucker*, that the common fly and other insects can move along ceilings, and even on polished surfaces of glass or metal, with their bodies hanging downwards; and there are many marine animals which attach themselves to rocks, or other objects, by a similar action.*

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* The prehensile arms or tentacles of the cuttle-fish are provided with suckers which act like dry cupping-glasses. Mr. Rymer Jones thus describes the mechanism for producing adhesion by means of these organs:—"From the margin of each cup or disk muscular fibres converge towards the centre, at a short distance from which they leave a circular aperture; behind this is a false floor that can be raised like the piston of a syringe, and thus produce a complete vacuum within the cup. So perfect is this mechanism for producing exhaustion, that while the piston continues raised, it is easier to tear away the sucker from the arm than to release its hold, but as soon as the muscular effort raising the piston ceases, the vacuum produced by its retraction is in an instant destroyed, and all the suckers detach themselves." —'Animal Kingdom,' p. 298.

The same mechanism is found on a still larger scale in the tentacles of the *Octopus*. One of them seen off Teneriffe in 1861 was from fifteen to eighteen feet in length. Its eight arms, each estimated at from four to six feet in length, were covered with suckers, and its weight was estimated at

When cattle "stick in the mud," or are "bogged," it is not so much the adhesion of the clay which prevents their extricating themselves, as the sucking resistance due to atmospheric pressure.

"*Atmospheric pressure on liquids.*"

418. The pressure of the atmosphere on liquids produces effects still more numerous and important than those now described on solids. As familiar examples we may refer to the working of pumps and syphons. All such phenomena were, in former times, referred to an imaginary cause, which was called *nature's horror of a vacuum*, or to an obscurely conceived *principle of suction.*

That there are fifteen pounds weight of invisible air above every square inch of the earth's surface, is proved by the effects on solids: and we now proceed to show that many of the apparently mysterious phenomena produced by air among liquids are but the necessary consequences of the same pressure acting upon them. In reference to some highly volatile liquids, such as ether and chloroform, the liquid state entirely depends on atmospheric pressure. Thus, when portions of these liquids are introduced into the Torricellian vacuum of a mercurial barometer (see Art. 427), they are instantly converted into vapour, and retain the vaporous condition so long as they are withdrawn from atmospheric pressure. For a similar reason all liquids are more rapidly vaporized, or converted into vapour, at a much lower temperature in the higher regions of the atmosphere than at the sea level.

It will facilitate the comprehension of the effects of atmospheric pressure on liquids, if we first review exactly corresponding effects produced by the pressure of liquids or palpable fluids one upon another.

If into the bent glass tube, A B C (fig. 116), mercury be poured to fill it to a height of about twenty inches, it will stand at exactly the same level, *a*, *c*, in both branches. (Art. 302.)

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four thousand pounds. In ordinary specimens the arms are like tapering thongs, about eighteen inches long, on each of which there is a double row of sucking disks. There are 240 of these suckers on each arm, making a total of 1920. The animal is thus enabled to seize and hold its prey with one set of arms, while by another set its body is firmly secured to the rocky cavity in which it lives. The larger sort would thus have the power of seizing and holding the body of a man beneath the water, and bathers in tropical seas are reported to have had some narrow escapes from the grasp of this sea-monster.

If water be then poured into the leg, B, it will depress the mercury surface there a certain distance, as *f*, and raise it just as much above *a* in the tube A; and the length and weight of the mercury in A, greater than in B, will indicate exactly the weight of water poured in; for the fluid masses in the two legs will always exactly balance.

It will be found that an inch of the mercurial column balances very nearly thirteen and a half inches of the water, proving, as is ascertained also by other means, described in Arts. 316, 335, that mercury is (in round numbers) thirteen and a half times heavier than water, bulk for bulk.

If equal weights or pressures of any kind be made on the level surfaces of mercury in the two branches, the level of these will not be disturbed; but any difference of pressure made will be immediately manifested and measured by the changed heights of the columns.

Now the atmosphere presses on the two surfaces described. An air-tight piston, *p*, with a valve in it that allows air to pass upwards, but not downwards, may be introduced into the tube A, and pushed down to the surface of the mercury at *a*, expelling all the air which rested on the mercury there. If that piston be then drawn up to near the top of the tube A, there will be no air left in the tube, or a vacuum will be produced there, while the atmosphere continues to press on the mercury within the other tube, B; and the difference of height or level between the depressed mercurial surface in B and the raised surface in A, which will be about thirty inches, ordinarily measures this atmospheric pressure. If the tube have an area of one inch square, the weight of mercury so raised would be nearly fifteen pounds, and is the exact weight of a column of equal size of air reaching from the earth to the top of the atmosphere. This admits of illustration in another form. A barometrical tube, one inch square, will sustain a column of mercury represented by thirty cubic inches in height. A cubic inch of mercury weighs half a pound, so that the whole column sustained by the pressure of the air weighs fifteen pounds, and as the tube represents a square inch

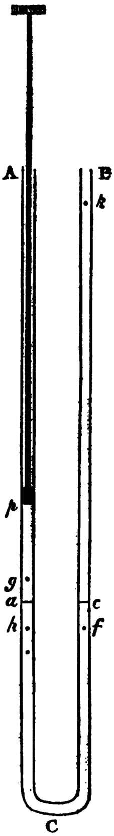

Fig. 116.

in area, this must be the amount of atmospheric pressure on each square inch of surface.

A similar experiment made in long tubes with water instead of mercury shows water pressed up thirty-four feet (in round numbers) into the vacuum, as should follow from the known difference of specific gravity between mercury and water.

The following examples further illustrate the reality and importance of atmospheric pressure as entering into the explanation of many phenomena of common observation :—

419. The common *lifting-pump* is merely a barrel, *a b* (fig. 117), with a close-fitting movable piston, *c*. When the lower end, *b*, is plunged into water, and the piston is drawn up from the bottom, the atmosphere being prevented from pressing on the surface of the water within the tube, the pressure on the water without the tube drives it up after the piston, just as if the piston dragged or attracted the water. That the water which thus rises may not fall again, there is a valve or flap at the lower part of the pump-barrel, *b*, which opens only to water passing upwards ; and that the piston may be allowed to pass downwards through the water in the barrel, to repeat its stroke, there is in it a similar valve. The piston, in rising during a second or succeeding stroke, causes all the water above it to run over at the spout, *d*. Formerly, a lifting-pump was said to act by *sucking* the water up from the well beneath it ; the true meaning of the phrase we now perceive to be, that *the piston merely lifts or holds off the air which was pressing on the water within the barrel, and allows the water to rise there in obedience to the pressure of the external air around.* The reason is apparent, then, why, in the suction-pump, the water will only follow the piston to a certain elevation, viz., until its weight balances the external pressure of the atmosphere.

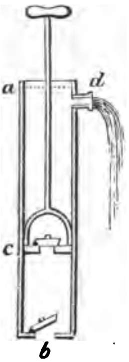

Fig. 117.

The word "suction" means originally an action of the mouth by which fluid is caused to enter it. It is a momentarily slight effort made to enlarge the cavity of the mouth, by which the pressure of the air confined within the mouth is rendered less than that of the external atmosphere, and, therefore, any fluid placed between the two pressures is moved towards the weaker. The mouth can make only a partial vacuum, and, therefore, cannot raise liquid very far.

The action of the common fire-bellows is of the same kind, as is also the action of the chest in breathing.

420. When the piston of a pump is solid, or without a valve, as at *c* (fig. 118), the machine is called a *forcing-pump*. The water rises beneath the piston, as already explained for the lifting-pump, but then, as it cannot pass through the descending piston, as in the lifting-pump, it is forced into any other desired direction, as to *d*. A forcing-pump can bring water from only thirty-four feet below the piston, but can send it to any elevation. In forcing-pumps, it is usual to make the water enter an air-vessel, *d a* (already explained in Art. 407), from which it is again urged by the elastic air, through the pipe, *b*, in a nearly uniform stream.

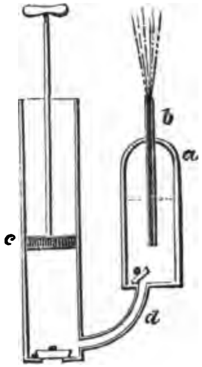

Fig. 118.

421. The *syphon* is an interesting application of atmospheric and fluid pressure. In its simplest form it is merely a bent tube, as *c b a* (fig. 119), with one end longer than the other. To use it, the short leg, *b c*, is first immersed in liquid, and the end, *a*, being stopped for the time by the finger or a cock, the whole tube is filled with liquid by applying the mouth to the end *d* of the small tube, *a d*, which is attached for convenience. If the end, *a*, be then left open, because a long column of liquid overbalances a short one, the liquid will run from the longer leg, and will continue to flow until the shorter has drunk up all within its reach. Whether the external extremity be in the air only, or immersed in liquid, makes no difference, except that the immersion shortens by so much the descending column. If both extremities be immersed in liquid, and in different vessels, by alternately lifting one vessel or the other, the liquid will be made to pass and repass, and will come to rest in the syphon only when the surfaces in the two vessels are at the same level. Thus the same leg becomes alternately the long or the

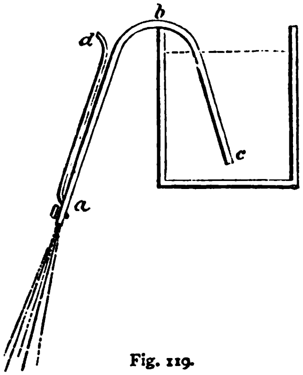

Fig. 119.

short leg, according to the height of the liquid in which it is immersed; for the length of the short leg must be estimated by the height of the bend above the surface of the supply liquid; and the length of the other is as much greater than this as its lower end, *a*, falls below this liquid surface.

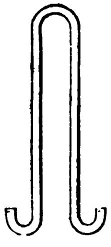

Fig. 120.

A syphon is sometimes made with both legs equal and turned up, as represented in fig. 120, so that it may remain full of liquid although lifted away from the vessel, and therefore may always be ready for action. As it is the same cause, atmospheric pressure, which lifts the water in a pump and in a syphon, the top of a syphon must evidently be within thirty-four feet of the water-surface below. In the syphon, as in the cases of balancing liquids, described in Art. 316, the comparative diameters of the legs is a matter of no importance, nor their oblique length, provided the perpendicular heights of the two columns have the necessary relation: even an inverted teapot might be used as a syphon, discharging at the spout.

422. The syphon is very useful for drawing off liquids, where there is a precipitate or sediment that should not be disturbed, or where it is desirable not to make an opening in the lower part of the vessel. A large syphon, or several smaller ones, would empty a lake or mill-pond over its bank without injuring the bank; or, it would lift a continuous stream of water like that of a great sewer in a town during repairs, over any obstacle of less height than thirty feet, therefore over a street or canal, and with no greater loss of speed than what takes place where a stream is made to dive on one side of an obstacle, in an underground channel which rises to the same level on the other side. To fill a large syphon with water so that it may act, a convenient way is, instead of pumping out the air from it, to close the two ends for the time, and to pour in water through a cock at the top.

The material of which the syphon is formed is of no consequence; it may be a flexible india-rubber tube, and bent into any number of tortuosities, the only condition being that the discharging end be lower than the liquid surface in which the other dips.

A few filaments of cotton, or glass threads, or fibres of asbestos may also be made to act as a syphon, the force of capillarity taking the place of the atmosphere in the sustaining of the liquid column. In this way a liquid may be slowly filtered drop by drop over the edge of a dish (see also Art. 86).

There is a pretty syphon-toy, called a *Tantalus-cup*, having in it a standing human figure which conceals a syphon. The short branch of the syphon rises in one leg of the figure to reach the level of the chin, and the long branch descends by the other leg, to pierce the bottom of the cup towards a reservoir below. On pouring water into the cup, the syphon begins to act as soon as the water reaches the chin of the figure, and the cup is then quickly emptied.

Among the infinitely varied water-channels or courses in the bowels of the earth, some are syphons, and produce what are called *intermitting wells or fountains*. These alternately run and cease for longer or shorter periods, according to the comparative magnitudes of the collecting reservoir and the channel. The reservoir may be an internal hollow of a mountain, receiving a regular supply of water by a slow filtering of moisture from above, and the discharging drain any syphon-formed channel, which, like that of the tantalus-cup, begins to act only when the water in the reservoir has risen to the level of the top of the syphon, and then carries off the water faster than it is supplied. There are some fountains that flow constantly, but at regular intervals have a remarkable increase. In them a common spring is joined with a syphon-spring.

423. The following facts have close relation to those now explained, as further illustrative of atmospheric pressure on liquids.

A long glass, full of jelly, if inverted and placed with its mouth just under the surface of warm water, will soon be found to have lost the jelly, and to be full of water in its stead. The jelly is heavier than water, and when melted by the heat, sinks down, and is replaced by water from below, forced up by the atmospheric pressure.

Some negro servants in the West Indies were once detected stealing rum, by the simple though ingenious trick of inserting the long neck of a bottle full of water through the top aperture of the rum-cask. In such case the water falls out of the bottle into the cask, whilst the lighter rum ascends in its stead.

The common water-glass for bird-cages has its only opening near the bottom through the neck, *b*, into the cup, *c* (fig. 121). Although full of water up to the level *a*, none descends, but when the surface in the open cup, *c*, falls so low that some air can pass into the glass by the channel, *b*, then a bubble of air does pass in and an equal bulk of water comes out, which, by again raising the water-level in the cup, prevents for the time the entrance of more air and the issue of more water. An ink-glass made on this principle preserves the ink very well, because there is so small a surface of the ink exposed to the air, while there is always the same depth of ink for the pen to be dipped into.

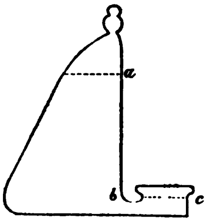

Fig. 121.

In the common *Argand* or *fountain-lamp*, a supply of oil to last for many hours is contained in a vessel like an inverted bottle, higher than the flame, with its mouth immersed in a small open reservoir of oil, nearly on a level with the flame. No oil can descend from above but as the flame consumes the free oil from the small reservoir, and by lowering its level allows a little air to rise and a corresponding bulk of oil to fall.

If, in a bottle or cask full of liquid and closely corked, a small hole be drilled through the bottom or side, the liquid will not rush out by that, because of the opposing pressure of the atmosphere, and because the opening is not large enough for a current of air to enter while the current of water escapes : but if a second opening be made in the top, a jet from the lower one will follow immediately, for then the atmosphere will press on the upper surface of the liquid as well as on the lower, and the weight of the liquid will be free to act. Thus beer or wine cannot be drawn from a cask by a cock placed near the bottom, unless what is called a *vent-hole* be made at the top. If the lower opening, however, be large enough to allow air to enter freely by one side of it, while the liquid is escaping by the other, the vessel may be quickly emptied as in pouring liquid from the mouth of an inverted can or jug. Through an opening of intermediate size there is a gurgling or contention between the entering air and issuing liquid, as is heard in decanting a bottle of wine or beer.

Even when there is a large opening at the bottom of a vessel which is close above, the liquid may be kept in by the pressure of the air, if the passing in opposite ways of the two currents of air and liquid, be rendered difficult. Thus an inverted bottle full of water will not discharge, if a piece of paper be simply applied against its mouth. So a wine glass or tumbler filled with water may be held with the mouth downwards, and yet none will be spilled, if a piece of note paper be laid loosely upon its mouth, and be properly supported during the turning. The pressure of the atmosphere against the paper keeps it steadily in its place, and supports the weight of the water above it. Any height of water less than thirty-four feet may be supported in this way.

424. *The animal body* is made up of solids and fluids, and is affected by the atmospheric pressure accordingly.

There is difficulty at first in believing that the human body can be bearing a pressure of fifteen pounds on every square inch of its surface, because we are altogether insensible of it; but such is the fact, and the reason of our not feeling it is, that the agent pressing is not a solid, urging only downwards, as one stone presses upon another, but is a fluid compressing uniformly all round (Art. 304). The amount of this pressure on the human body may be estimated from the following statement :—Fifteen pounds on a square inch are equivalent to 2160 pounds, or nearly a ton, on a square foot. The body of an adult is calculated to have an area of about fifteen square feet, and the actual pressure which it sustains from the atmosphere is equivalent to 32,400 pounds, or nearly fifteen tons. This pressure is equal on every side, and inside as well as outside; hence it is not perceptible.

The thinnest bladder weighs the same whether full of air or empty, and when full it is submitted on its exterior to a pressure of many hundreds of pounds, but the air which it encloses being under the same amount of pressure as that which is on the outside of it, it is neither torn nor rent, in this respect resembling a sheet of the thinnest tissue paper immersed in water. So long as the water presses above and below, the sheet of paper preserves its cohesion; but if the water pressed only on one side, it would be immediately destroyed.

The following experiment will show that the pressure is equal on all sides. Fill a jar, well ground at the edge, with carbonic acid gas. Pour into the jar a small quantity of a strong solution of potash, cover it immediately with plate glass, and agitate the vessel. The carbonic acid will be removed by the potash, and as there is now nothing to counteract the pressure of the atmosphere on the outside, the plate glass is firmly fixed to the jar, and remains so fixed whether the jar be held with its mouth upwards, downwards, or sideways. The jar may be lifted by the glass plate, and it will require a violent effort to remove it.

it is by reason of this pressure that air penetrates into all liquids and porous solids. Water, as well as mercury, contains it. Cork owes its buoyancy to it, for the specific gravity of cork, deprived of air, is half again as great as that of water.

A pressure of the same kind, even many times greater, such, for instance, as fishes bear in deep water, or as a man supports in a diving-bell, equally remains unnoticed. Fishes are at their ease in a depth of water, whose pressure would instantly crush inwards almost the strongest empty vessel that could be sent down; and men walk on earth without feeling the pressure of an atmosphere about them, which is heavy enough instantly to crush together the sides of a square glass bottle when emptied by the air-pump, or even the substance of a thick iron vessel, left for a moment by any accident without the counteracting internal support of steam or air.

The fluid pressure on animal bodies, thus unperceived under ordinary circumstances, may be rendered instantly sensible by artificial arrangements. A person may without any peculiar sensation apply the hand closely to the mouth or opening of any vessel containing air, but the instant the air is withdrawn from within the tube or vessel, the then unresisted pressure of the external air fixes the hand upon the opening, causes the flesh to swell or bulge into it, and makes the blood ooze from any crack or puncture in the skin. This description corresponds with the surgical operation of *cupping;* the essential circumstances of which are, the application of a cup or glass, with a smooth blunt lip, to the skin of any part of the body, and the extraction by a syringe or other means of a portion of the air from within the cup.

425. This may be easily understood, by considering what would happen to a small bladder or India-rubber bag full of any fluid, and pressed between the hands on every part of its surface except one. At that one part the bag would swell out, and would even burst if the pressure were strong, while no other part would suffer. So it is in cupping: the whole body, except the surface under the cup, is squeezed by the atmosphere, with a force of fifteen pounds to the square inch, while in that one situation the pressure is diminished according to the degree of exhaustion in the cup, and the blood consequently accumulates there, causing great swelling. The application of cups with exhaustion only, constitutes the operation called *dry-cupping.* To obtain blood, the cup is removed and the tumid part is cut into, by the slight stroke of a number of lances united; and the cup being then applied again as before and exhausted, the blood streams forth under the diminished pressure. The partial vacuum in the cup may be produced either by the action of a syringe, or by burning a little spirit in the cup, and applying it while the momentary dilatation effected by the heat has driven out from it the greater part of the air. The human mouth applied upon any part becomes, by the action of sucking, a kind of cupping apparatus, and, in cases of poisoned wounds, has been used at the instant as such. The mouth of a leech presents such an apparatus. It is provided with three sharp cutting tubercles, which make three wounds at once of a somewhat triangular shape. The mouth is the body of the pump, and the tongue, or fleshy nipple, is the sucker. By the working of this piece of mechanism the blood is made to rise up to the conduit, which conveys it into twenty-four small cells forming the stomachs of the animal.

There is a mode of modifying more extensively the atmospheric pressure on the human body, as a remedy, which will be described in the medical appendix.

426. The atmospheric pressure on living bodies produces an effect which is rarely thought of, although of much importance, viz., keeping all the parts about the joints closely together by an action similar to that exerted on the Magdeburg hemispheres, or on the united corks described at Art. 415. The broad surfaces of bone forming the knee-joint, for instance, if not held together by ligaments, could not, while the capsule surrounding the joint remained air-tight, be separated by a force of less than about a hundred pounds; but on air being admitted to the articular cavity, the bones at once fall to a certain distance apart. In the loose joint of the shoulder, this support is of great consequence. When the shoulder or other joint is dislocated, there is no empty space left there, as might be supposed, but the soft parts around are pressed in, to fill up the natural place of the bone. When a thigh bone is dislocated, the deep socket called the acetabulum instantly becomes like a cupping-glass, and is filled partly with fluid and partly with the soft solids. In all joints it is the atmospheric pressure which keeps the bones in such steady contact, that they work smoothly and without noise. These important facts had escaped observation until pointed out in the first edition of this work.

THE BAROMETER.

427. We have seen that a column of liquid is supported in an otherwise vacuous tube to a certain height, depending on the density of the liquid, and that this can be explained only by reference to the pressure of the atmosphere. Such a contrivance then becomes an exact measure of the degree of this pressure, and is called a *barometer*. Its importance, both in a scientific point of view and in the business of common life, renders an account of its principle one of the most interesting parts of natural philosophy.

The steps leading to the invention of the barometer were nearly as follows:—Galileo had, about the year 1642, found that water would not follow the piston of a pump to a height greater than about thirty-two feet, and this sudden limit to nature's horror of a vacuum, which had been the unchallenged explanation of the rise of water in a pump hitherto, was perplexing to the mind of the philosopher. It is not known whether the true solution of the difficulty occurred to Galileo; at any rate, the honour of establishing the theory that the cause was the atmosphere pressing by its weight falls to his pupil, Torricelli. Reasoning that mercury, being a fluid thirteen and a half times heavier than water, should be supported to a height thirteen and a half times less than water, he tried and found it was so, and thus the mercurial barometer was invented. Torricelli's experiment was as follows:—He filled with mercury a glass tube, closed at one end, and about three feet or forty inches in length, and then stopping the open end with his finger, he inverted it, and placed it with this open end under the surface of a basin of mercury. On removing his finger he found that the mercury fell down from the end of the tube, and stood at about thirty inches above the level of the mercury in the basin. Torricelli thus proved that the weight of this mercurial column was identical with that of the water column which could be supported within the barrel of a pump, and that both must be balanced by one and the same counterpoise, viz., the weight of the air. Shortly after the discovery Torricelli died, and Pascal completed it, by carrying the tube of mercury to the tops of high buildings, and of church towers, and up the sides of mountains, when he found that the mercurial column fell always in proportion to the ascent. He found, for example, a depression of more than three inches in the height of the mercurial column at the top of the mountain named Puy de Dôme, in Auvergne, compared with its height at the base of the mountain.* He found, also, that water-pumps varied as to sucking power at different elevations, according to the same law.

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* This important experiment was performed in the year 1648. Two barometers were employed. At the foot of the mountain, prior to the ascent, the mercury in each stood at 28 inches. One of them was carried to the summit, and the mercury was observed to fall to 24·7 inches. On

Thus, with great hesitation, and almost timidity, did the most distinguished philosophers of little more than two centuries ago abandon their old beliefs that the atmosphere extended as far as the moon, and that "nature abhors a vacuum;" and so accept a new doctrine which was to revolutionize the explanations of a multitude of the most important natural phenomena.

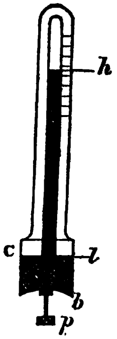

Fig. 122.

428. Various modifications on the form of the mercurial barometer have been devised from time to time, but in principle they are all identical with the simple upright glass tube which we have just described.

(i.) *The standard or cistern barometer* is a Torricellian tube, *h l* (fig. 122), inverted in a cistern, C, containing mercury. The height, *h* (read off on a scale by the side of the tube), gives the length of the mercurial column supported by the weight of the atmosphere. This weight is subject to constant variations, as we shall notice presently; and, in consequence, the top of the column in the tube rises and falls, and the level of the mercury in the cistern, which should be the zero of reckoning for the true height, will sometimes correspond with the zero of the scale, and sometimes not. To avoid the correction in reading which this would involve, the bottom, *b*, of the cistern is sometimes made flexible, as of leather, so that by a screw pin, *p* (fig. 122), it can be raised or lowered till the level, *l*, in the cistern always corresponds with the zero of the scale.

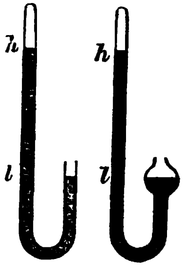

Fig. 123.

(ii.) *The syphon barometer* (fig. 123) is another common form of the instrument. It was suggested by Torricelli as a more convenient form than the

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descending, Pascal observed that the column of mercury gradually rose, and finally reached its former height, 28 inches. The difference of pressure, therefore, at the base and summit of the mountain amounted to about 3·3 inches, and a decrease of one inch of pressure within a certain limit is equivalent to about 1000 feet of elevation. It thus appeared that the summit of the mountain was between three and four thousand feet above its base. The ascertained height of the Puy de Dôme, which is an extinct volcano, is 3565 feet.

basin and tube. The height, *h l*, is measured by the difference of level in the two branches of the tube; and sometimes the end of the shorter leg is widened out, as in the second of the two figures, to diminish the amount of error made by always reckoning from the same zero point.

(iii.) The *Wheel Barometer*, represented in fig. 124, is perhaps the most familiar form of the mercurial barometer. A little mass of metal, D, is made to float on the surface of the mercury, and by means of a thread passing over a pulley, E, and a balancing weight, the rise and fall of the mercury in the tube is made to turn an index hand, F, like the hand of a clock, which points to the degree of elevation. Its chief defects are the interference of friction at the float D, and at the pulley E, which renders it necessary to tap the barometer before we can be sure that the hand corresponds to the exact position of the float D, just on the surface of the mercurial column. Thus it is totally unsuited for accurate reading.

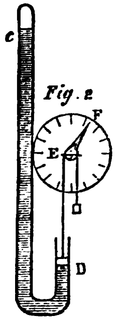

Fig. 124.

A great number of modifications of these forms have been proposed, such as inclining the long leg of the syphon so that an inch of vertical rise of the mercury shall correspond to two or three inches of motion of the mercurial column along the tube; or contracting the diameter of the lower part of the tube, so as to adapt the instrument to use on board ship, the increased friction of the liquid in the narrow part preventing the spilling of the mercury by the rolling and pitching of the vessel (see also Art. 152), but diminishing of course in a corresponding degree the sensibility of the instrument to variations of atmospheric pressure; whence the marine barometer used on shore will generally be twenty minutes or half an hour behind an ordinary standard one in indicating an atmospheric change of weight.

We know, from the laws of hydrostatics already explained, that the size of the tube is of no importance; the atmospheric pressure would equally sustain a mercurial column to a height of 30 inches, though it were a foot instead of an inch in diameter. It is always desirable, then, to have the tube as large in section as is convenient, the column being thereby less influenced by friction, and by capillary depression of the top (Art. 88).

In the construction of barometers, mercury is the most suitable liquid, because of its great specific gravity, a column of mercury of about 31 inches serving where a column of water would have to be 35 feet, and of oil 38 feet. Water barometers have, however, been constructed, with the aim of showing the variations of atmospheric pressure more markedly, an inch of fall of the mercury corresponding to a fall of 13½ inches of the water barometer; but there are serious difficulties, as well as their unmanageable size, which prevent their being of practical service for any length of time.

429. The *Aneroid*[*] barometer is a modern invention, due to a Frenchman, M. Vidi, which rivals in sensibility and far surpasses in convenience and portability all the forms of the mercurial barometer. To the navigator who knows how to use it, it is an inestimable boon, being unaffected by the oscillations of the ship. The heights of balloon ascents are now calculated by means of these; and, furnished with a good pocket aneroid, the holiday traveller may often be warned to provide against approaching atmospheric changes which might otherwise surprise him on his excursions, or he may readily ascertain the height of any mountain which he ascends.

The aneroid consists essentially of a small metal drum or box, whose ends are closed with a thin corrugated elastic metallic plate. It is nearly exhausted of air and then hermetically closed. The variations of atmospheric pressure cause the elastic ends of the drum to approach or recede; and, by a combined lever arrangement, this motion is communicated to a chain resembling a watch-chain, which passes round the arbour of an indicating hand. The hand points to figures round the dial plate of the instrument corresponding to the height of the mercurial barometer, with which the aneroid, however good, ought to be compared, from time to time, and adjusted by means of a regulator screw which is usually attached.

Somewhat analogous to the aneroid, is *Bourdon's metallic barometer*, which is a flattened elastic tube of metal, bent into the form of an arc of a circle, and entirely exhausted of air. Variations of the atmospheric pressure cause the ends of this circular arc or tube to approach or recede, and the motion is communicated to an indicating hand, in much the same way as for the aneroid. This has the advantage of being applicable to show gaseous pressures twenty to thirty times greater than that of our atmosphere.

[*] The name is derived from two Greek words, ἀ, not, and *νηρος*, liquid, because no liquid is employed in its construction.

Use of the Barometer as a Weather-glass.

430. The civilized world is now so familiar with the barometer, that we can hardly conceive the wonder and delight with which men of science of two hundred years ago gazed at the suspension of the mercury in the Torricellian tube. Simple as it now appears, it opened the eyes of that generation to changes in the condition of the unsubstantial air, as it had been called, of which they had never dreamed, and which to the unaided senses are altogether impalpable. The famous Italian experiment threw a sudden blaze of light over the whole of physical science.

Simultaneously almost with the invention of the barometer, it was observed that the height of the mercury was constantly fluctuating, and that storms and marked changes of weather were almost invariably accompanied with variations of the height of the mercury. Hence, though the connection between the state of the weather and the behaviour of the barometer was not apparent, it was looked upon as a *weather-glass*, and an instrument consequently of the highest practical importance.

As it is very common to regard the barometer with a sort of superstitious reverence, it may be as well to give some idea of its real value and use as an index to weather changes. From a variety of causes, to be specially noticed afterwards—such as the periodical heating of the sun's rays, aerial currents or winds, &c.—the weight of the atmosphere at any place is found to vary from day to day, and even from hour to hour. Sometimes it is sufficient to support a column of thirty-one inches of mercury, at other times of only twenty-seven or twenty-eight inches, the mean or average height in this country being almost exactly thirty inches.

On watching the oscillations of the barometer from time to time, there is perceived, in the first place, some general connection between the hour of the day and the height of the mercury. Especially regular are these daily variations at the equator and the tropics, where the climate is less complicated and uncertain than in our northern latitudes. In the tropics, the mercury gradually sinks every day, almost with the regularity of a clock, from noon till about four in the afternoon, when it is at its lowest; it then slowly rises till about ten in the evening, when it reaches its greatest height; during the night it keeps sinking till, about four in the morning, it again reaches a minimum; and lastly, it once more rises till its maximum is attained at ten in the morning. Now the hours of maximum and minimum barometer readings coincide almost exactly with those of minimum and maximum *thermometer* readings respectively; and it has been inferred from this correspondence, that the diminished pressure is due to the heating of the air by the sun's rays, which causes it to ascend, and so lighten the weight at the surface of the earth beneath.

This explains also the fact that the mean or average height of the barometer is higher in the winter than in the summer months, a statement contrary to the generally conceived relation between the weather and the height of the barometer.

The following general rule has been inferred from the regular diurnal variations of the barometer, and has been found to accord with a large number of observations:—

If the motion of the mercury be contrary to the regular motion—as, for instance, if it rise instead of falling between ten o'clock in the morning and four o'clock in the afternoon, or if it fall instead of rising between the latter hour and ten o'clock in the evening—then weather-changes may with great probability be predicted; and in general, fine weather for the former change and rain for the latter.

431. It will be more particularly explained a few pages hence (Art. 448) that the atmospheric disturbances are most irregular over the *temperate* zones of our globe; from the number of varying elements that enter into the determining cause, the weather in those regions may be said to defy anticipation; and the value of the barometer, or of any contrivance which might indicate weather-changes even a single day beforehand, would of course be inestimable to the inhabitants of the countries which have such a changeable climate.

The absolute height of the barometer, it is to be noted, does not at any place indicate a special state of the weather; much less do the weather-indications for one place apply to another place, whose conditions of climate are dependent on a wholly different geographical situation.

As a general rule, however, *rain*, *storms*, and *remarkable changes* of weather are accompanied with marked alterations of the barometer, although sudden depressions of the mercury may sometimes occur even in calm weather. On an average the daily range of the mercurial column up and down, does not exceed one-tenth of an inch; whereas it has been often known to fall, within a single hour, half-an-inch or more on the approach of a violent storm.

Otto von Guerike, the inventor of the air-pump, records an observation that he made with a water-barometer in the year 1660. The index of his barometer, which was the tiny figure of a man floating on the top of the column of water, had descended one day below the lowest part of the glass tube, which usually exposed the upper part of the column. On this he confidently affirmed to a friend that a storm must be raging somewhere; and within two hours, he says, a terrific tempest burst over the city of Magdeburg.

It is said also that on the occasion of the great Lisbon earthquake of 1775, the mercury in the barometers, even in Britain, fell so far as to disappear from the portion at the top usually left uncovered for observation.

But it is only within comparatively recent times that anything like clear ideas have been formed as to the real character of the atmospheric disturbances which we call storms. By the comparison of barometric readings regularly observed at a large number of stations, which has been greatly facilitated by the free telegraphic intercommunication of our day, some interesting and important laws have been found to rule the course of even the fickle wind.

432. The air, being a fluid, will, in accordance with the laws of fluid motion already considered, always move from a place of greater to one of less pressure; or, in other words, *the direction of the wind will indicate the relative situations of places of different atmospheric pressure.* The barometer, consequently, is not only the pressure gauge of the atmosphere, but also a wind gauge.

A difference of $\frac{1}{20}$th or $\frac{1}{10}$th of an inch in the height of the mercury at two stations 100 miles apart, measures the inequality of aerial fluid-pressures there; and if a series of barometers were set up between the two spots, the tops of their mercurial columns would obviously form a curved slope, more or less steep according to the difference of barometric pressures at the two places. By modern meteorologists this curve is called the *barometric gradient.* The air would flow from the top towards the bottom of this gradient, or from places of high to places of low readings, and this flow constitutes *wind.* A gentle wind will therefore correspond to a gentle gradient of the barometer towards the quarter from which it blows.—Of course it is not spots, but *areas* of different pressures that we have actually to deal with in nature; but we have merely to alter the language to adapt the foregoing statements to fact.

Many causes operate to produce temporary differences of atmospheric pressure; consequently, there will often be several areas of high and of low atmospheric pressure, some accidental or temporary, others more permanent in their character. Upon the extent and relative situation of these will depend the intensity, direction, and extent of the resulting winds or storms.

If the barometer stands high, then we know that the pressure cannot be very much greater anywhere round about; in general it will be less; thus a *high* barometer will be usually accompanied with moderate *outward* aërial currents : while for a similar reason, a *low* barometer will be most probably accompanied by a wind of greater or less force blowing *inwards* from surrounding heights.

From this it will be readily understood that a single barometer can be of little service in forecasting the weather, because everything will depend on the relative barometric condition of the surrounding area. A *steady* barometer, however, will indicate an *area of uniform pressure*, and if this has been suddenly attained, the probability is that the area is but small; whereas, on the other hand, if the change of barometric level has been slow, it is very probable that there is a large area of uniform level, and that there will consequently be but slight change of weather one way or another. Everything depends on the sizes and shapes of the areas of pressure; and many of the seeming exceptions to rules for foretelling the weather, are due to interferences of small temporary areas of high or low pressure, caused by special local conditions.

433. These theoretical explanations admit of ready confirmation by the invaluable method of *mapping* meteorological observations.

By this system, which is quite a modern feature of meteorology, the areas of barometric elevation or depression over a larger tract of country, or over a whole continent, can be seen at a glance. A great number of observing stations having been selected, say over the continent of Europe and the British Isles, telegraphic reports of the barometer-readings at set hours of the day are transmitted from all of them to a few head-centres such as London, Paris, Berlin, &c. There these observations are collected and assorted, and lines being drawn upon a map through all the stations where the barometer stands at the same point, mark the areas of equal atmospheric pressure. Such lines, called *isobaric* lines, or lines of equal barometric height, present many curious features. Very often the curved line makes a complete round, enclosing a whole tract of country over which the air-pressure is uniform; in such cases, where a whole region of barometric depression is enclosed, it is almost always an index of violent atmospheric disturbance, the wind rushing in from all sides round about to equalize the pressure.

A most remarkable fact is that the wind in rushing towards such depressed areas goes, not directly, but with a vortical or whirling motion; and the following law seems to be pretty firmly established :—

> That the passage of aërial currents between centres of unequal pressure is never in a direct line, but with a sort of spiral motion towards the centre of low pressure, and that *storms* in general have such a circling or spiral course. This is seen on a tremendous scale in the cyclones, tornadoes, and whirlwinds which are the special terror of tropical latitudes.

But the complete discussion of the law of storms, as discovered by modern observations of the barometer, belongs to the science of *Meteorology*. The value of such knowledge is recognized by most civilized governments of the present day : and it is of special importance to countries like our own which have an extensive maritime commerce.

A sum of £10,000 is voted annually by the British Government to the Meteorological Committee of the Royal Society for the collection and distribution of meteorological information. Charts with isobaric lines, and a number of other weather-elements, are now printed and issued twice a-day in London, and telegrams of storms which are known to be raging elsewhere, with indications of their probable course, are sent daily to the principal seaports of the kingdom.

From the preceding remarks it will be understood, then, that the words usually marked on barometers for popular use, such as *Fair* (at 30 inches), *Change* (at 29½ inches), *Rain* (at 29 inches), *Stormy* (at 28 inches), are by no means absolutely reliable ; for a low reading of the barometer may be accompanied with fine weather and a high reading with wet ; if, in the former case, the mercury be inclining to rise, and, in the latter, inclining to fall. It is the recent *changes* in the barometer, and its height comparatively to that in the surrounding country, that form the most trustworthy monitor of "what a day may bring forth."

> **434.** The barometer answers another important purpose, viz., that of enabling us to ascertain readily the heights of mountains, or of any situation to which it can be carried.

We have seen (Art. 427) that one of the first observations with the barometer was, that the column of mercury falls as we ascend. This we might at once expect, seeing that the atmosphere has but a limited weight, and consequently can have but a limited height. For if thirty inches of mercury mark the whole atmospheric pressure at the level of the sea, and if the instrument, when carried to some other situation, stand at only twenty inches, it is obvious that one-third of the substance of the atmosphere exists below the level of the new situation.

Now if the atmospheric ocean were of as uniform density all the way up as an ocean of water, a certain weight of air thus left behind in ascending would mark everywhere an equal change of level, and the ascertaining of any height by the barometer would be a very simple calculation. The air at the surface of the earth being about 11,000 times lighter than its bulk of mercury, an inch rise or fall of the barometer would mark everywhere an ascent or descent in the atmosphere of 11,000 inches or about 900 feet. Owing to the elasticity of air, however, which causes it to increase in volume as it is relieved from pressure, the atmosphere is rarer in proportion as we ascend; so that, to leave a given weight of it behind, the ascent must be greater, the higher the situation where the experiment is made. In other words, the heights corresponding to equal falls of the mercurial column are constantly increasing. The rule, therefore, of one inch of mercury for 900 feet, holds only for rough estimates near the surface of the earth. The more precise calculation for any case, is still easy; and a good barometer, with a thermometer attached, and with tables, or an algebraical formula expressing all the influencing circumstances, enables travellers to ascertain elevations much more readily, and in many cases more correctly, than even a trigonometrical survey.

"*The limits of the Atmosphere.*"

435. The weight of the whole atmospheric ocean surrounding the earth being equal to that of a covering of mercury of thirty inches, and the air at the surface of the earth being about 11,000 times lighter than mercury, if the same density existed all the way up, the atmosphere would be thirty times 11,000 inches high, equal to somewhat over five miles. On account of the greater rarity, however, in the superior regions, it really extends many times higher than this. Some would estimate its limit at fifty miles, while others have calculated that it cannot be less than 200 miles. Some would even have it that there may be no limit to the rarefaction of air as we ascend; but the atomic hypothesis of matter, coupled with the observations of astronomers upon the effect of the atmosphere in altering the direction in which a star appears, renders it most probable that there is a definite limit at which the expansive force of the air will be just balanced by the earth's attraction for it.

In a barometer carried from the level of the Thames to the top of St. Paul's Cathedral, or of Hampstead Hill, the mercury falls nearly half an inch, marking an ascent of about 450 feet. On the summit of Mont Blanc it falls to half of the entire barometric height, marking an elevation of 15,000 feet; thus proving that one-half of all the atmospheric envelope surrounding our globe lies within 3½ miles of its surface.

Speaking roughly, it may be stated that, at a height of 3½ miles the barometer will stand about 15 inches, while at double that height, or 7 miles, it will be reduced to half this height, or 7½ inches; and again, at triple this, or 10 miles, it will be reduced to 3¾ inches; or generally that *for every 3½ miles of ascent, the height of the barometric column will be halved.*

This diminution in the density of the upper strata of air is very strikingly and often painfully proved to those who have made the ascent of lofty mountains such as Mont Blanc, or who have rapidly ascended in a balloon to any considerable height. It has been observed that breathing begins to be very difficult at an altitude of about 20,000 feet. The hardiest mountaineers of the Andes cannot walk ten paces at an elevation of 16,000 feet without resting after each effort. In Quito it is found to be difficult to make the horses and mules advance at heights above 13,000 feet. They stand still, tremble all over, and fall upon the ground, and if not allowed to rest they die. In all these cases there is muscular exertion; but in balloons, where the necessity for this does not exist, a height of 23,000 feet has been attained on several occasions without involving much suffering. In 1805 this altitude was reached in a balloon by the eminent chemist, Guy Lussac, and a similar height has been since attained on several occasions by Mr. Glaisher and other aëronauts.

A person breathing on the summit of Mont Blanc, although expanding his chest as much as usual, really takes in at each inspiration only half as much air as he does ordinarily—exhibiting the contrast to a man in a diving-bell, who, at 34 feet under water, is breathing air of double density, at 68 feet of triple, and so on. It is well known that travellers, and even their practised guides, often fall down suddenly or faint when approaching lofty summits, on account chiefly of the thinness of the air which they are breathing, and some minutes elapse before they recover. It appears from all this, that although our atmosphere is from 45 to 50 miles high, it is so thin beyond three and a half miles, that mountain ridges of greater elevation are nearly as effectual barriers between nations of men, as islands or rocky ridges in the sea are between the finny tribes inhabiting the opposite coasts.

At a distance of eight miles above the surface of the earth, there is reason to believe that the air would be too much rarefied to sustain animal life. The highest point which a balloon has reached, is stated to have been seven miles. This was in an ascent made in 1862 by Messrs. Glaisher and Coxwell, when their balloon, which had a capacity of 90,000 cubic feet, reached a height of 37,000 feet, or about seven miles. Mr. Glaisher was able to make observations up to a height of 19,000 feet, at a time when his companion was panting for breath. At 29,000 feet Mr. Glaisher's eyesight failed, although his sense of hearing and other mental faculties were retained a little longer. His muscular powers were, however, quite gone, and his companion felt a general numbness, and was partly paralyzed by the severe cold.

It would seem, therefore, that in elevations above four miles a man loses the power of making any correct observations. Lower elevations have been frequently reached without dangerous consequences; but there is considerable risk when the transition from the lower to the higher strata of the atmosphere is made suddenly. Under these circumstances, apart from the numbing effects produced by severe cold, fatal asphyxia or suffocation may occur, owing to the lungs not having the power to accommodate themselves to the sudden change in the density of the air.

The tragical results of the ascent of the 'Zenith' balloon in April, 1875, thus admits of explanation. MM. Sivel, Tissandier, and Croce Spinelli made an ascent in France for the purpose of determining the amount of carbonic acid and aqueous vapour in the higher regions of the atmosphere. The rate of ascent at first was nine feet in a second, but it diminished gradually. In an hour and a half the balloon had reached the altitude of 22,800 feet, rather more than four miles. They had taken oxygen with them, which they breathed with good effect. Some ballast was thrown over. They ascended rapidly, and M. Tissandier fainted. When he recovered he threw over more ballast, and M. Spinelli at the same time, apparently unconsciously, threw over the aspirator, an instrument weighing eighty pounds. This must have caused a sudden and rapid ascent of the balloon. M. Tissandier fell asleep for an hour, and when he awoke he found the balloon rapidly descending, and no more ballast was left. His two companions were lying dead, their faces black, and blood flowing from the mouth and nose. They had died from suffocation, no doubt caused by the sudden transition to a rarefied atmosphere at a great elevation. The maximum height marked by the instruments in the balloon was 27,950 feet, or rather more than 5 miles. The subsequent descent of the balloon was owing to a rapid escape of the gas as a result of expansion.

436. A barometer connected with an air-pump, is used as a *gauge* to indicate the progress and degree of exhaustion in the receiver, and is a necessary addition to a good air-pump. When the mercury falls to half its average height (15 inches), it shows that half of the air is extracted; and so for all other proportions. As the chief purpose of the gauge is to show when the exhaustion is carried nearly to completion, a very short tube, corresponding to the bottom of a common barometer, is all that is generally provided, and it is usually made of the bent or syphon form.

437. An ingenious method, devised by Sir John Leslie, of ascertaining the absolute specific gravity of any porous mass or powder, is an application of the barometric or Torricellian tube. Its principle may be stated thus. The interstices of a porous or pulverized mass are filled with air of the density of the surrounding atmosphere, and if the atmospheric pressure upon the mass, on which that density depends, be diminished in any known degree, an exactly corresponding proportion of the air will issue from the pores. This proportion being known, the whole volume of pores in the mass can be easily determined.

Leslie's mode of operation is as follows :—

An open glass tube, *a e* (fig. 125), of known dimensions, has a part of its top, *a b*, prepared as a receptacle for the substance under trial, a partition being affixed at *b*, so as to support the substance, but allow passage to air. Having then put the substance in *a b*, we gradually immerse the tube in a vessel of mercury, *d f*, until the mercury stand both inside and outside of the tube at the level of *b*, the air from the tube having passed out at *a* through the substance in *a b*. It is evident then that on closing the tube at *a* by a stopcock, and lifting the tube, a column of mercury will remain standing in it, above the level of the external mercury at *d*, and will be acting as a piston pulling down from *b* with force proportioned to its height. If the tube be lifted until the column *c d* be just half the length of the column in a common barometer, the air in the pores of the substance will be relieved from half of the atmospheric pressure, and will dilate to double bulk ; so that while half of the air will remain in the pores, the other half will have issued forth to occupy a space, as *b c*, between the surface of the mercury and the partition at *b*. This space, *b c*, therefore, will be exactly equal to the amount of the pores or interstices ; and as it may be measured and compared with the whole space, *a b*, its ascertained magnitude will solve the problem. It has been found in this way that charcoal, which is usually said to be only half as heavy as its bulk of water, is really formed of matter nearly four times as heavy ; proving, in a new way, the identity of charcoal and diamond : and that light pumice-stone consists of matter as heavy as granite or marble.

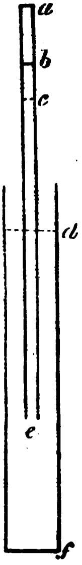

Fig. 125.

438. A barometer is of great use to persons employed about those mines in which the light *carburetted hydrogen gas*, or *fire-damp*, is copiously generated and is collected in the hollows or the excavations. When the atmosphere becomes unusually light, the gas being relieved from a part of the pressure which ordinarily confines it to its holes and lurking-places, expands or issues forth to where, mixed with common air, it may meet the lamp of the miner, and explode to his destruction. In heavy states of the atmosphere, on the contrary, it is pressed back to its hiding-places, and the miner may advance with comparative safety.

We see from this that any reservoir or vessel containing air would itself answer as a barometer, if the only opening to it were through a long tubular neck, containing a close-sliding plug with little friction ; for then, according to the weight and pressure of the external air the density of that in the vessel would vary, and all changes would be marked by the position of the moveable plug A barometer has actually been made on this principle by using a vessel of glass, with a narrow horizontal neck, in which a globule of mercury has served as the movable plug.

439. The pressure of the atmosphere determines, as it has been elsewhere stated, the liquid condition of many substances, which, but for this weight pressing on them, would spontaneously turn into vapour or gas. (See Art. 418.) The discussion of this, as well as of the boiling of water, and the formation of steam, is so closely connected with the present subject that it might naturally be entered upon here; but as these phenomena are all intimately related to heat, and can be more satisfactorily explained in that connection, the reader is referred for them to the subsequent section on HEAT.

440. Among important effects of atmospheric pressure may be mentioned the following:—

Water contains always more or less air mixed up with it, and kept there by the pressure of the atmosphere. This rises from the water at once on taking off the pressure. If we place a glass of common water under the receiver of an air-pump and then exhaust the receiver, the water is soon filled with bubbles of air, which are seen adhering to the surface of the glass all around, or rising through the water. This admixture of air with water is necessary to the life of fishes. Such air is driven off by boiling, and hence water that has recently been boiled has a vapid taste, and is unfit to support the life of fishes.*

In the production of beer, wine, and other fermented liquors, there is formed, during fermentation, some alcoholic spirit, and a large quantity of carbonic acid gas. Much of this last escapes, but, because of the pressure of the atmosphere, much still remains in union with the liquid. On removing this pressure suddenly, the liquid appears almost to boil, as when a glass of warm beer is placed under the exhausted receiver of an air-pump.

A greater pressure than that of the atmosphere keeps a proportionally larger quantity of this carbonic acid in liquid combinations; as in bottled porter or sparkling champagne, before the confining cork is drawn; as soon as the cork is removed, the gas escapes, causing the thin champagne to sparkle, and the comparatively viscid beer, which retains more strongly the little air-bubbles as they rise, to be covered with froth. This sparkling or frothing may be renewed by placing the glass under the air-pump receiver, or by warming the glass ; hence the sharp sensation of champagne in the warm mouth.

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* If a portion of charcoal or pumice be sunk in distilled water by a leaden weight, it will be found on placing the vessel under the receiver of an air-pump that a large quantity of air escapes at each movement of the pump from the two ends of the charcoal and the pores of the pumice. A stick of charcoal heated to a high temperature and plunged under mercury is filled with the liquid metal by atmospheric pressure in the act of cooling The circular rings of the wood are filled with silvery globules.

Carbonic acid so readily becomes liquid when its attraction for water assists the compression used, that enough of it may be united with water to make a pint of water become a pint and a half of compound liquid. The soda-water, or aërated water, now so generally used as a cooling drink in warm weather, is water with twice or thrice its bulk of carbonic acid forced into it by pressure ; a part of this gaseous acid is seen beginning to escape the instant the cork is drawn.

Carbonic acid forms nearly half of the substance and weight of marble or lime-stone. When an acid with stronger attraction for lime, as vinegar or sulphuric acid, is poured upon marble, it displaces the carbonic acid, and unites with the pure lime. The carbonic acid in rising, constitutes the effervescence which then appears. Carbonic acid for the manufacture of the common soda-water and other aërated drinks, as well as aërated bread, is obtained from chalk or marble by the action of sulphuric acid.

The Buoyancy of Air.

441. It was explained under Hydrostatics (Art. 317), that any body immersed in a fluid is buoyed up with exactly the force which supported the quantity of the fluid previously occupying the same space, and therefore that a body will sink or swim in any fluid according as it is heavier or lighter than its bulk of the fluid. These remarks are as applicable to the case of a body immersed in air or gas as to that of a body immersed in water or any other liquid.

Thus a body weighed by a spring-balance in air appears lighter by the weight of its bulk of air, than when weighed in a vacuum; and for the same reason, the jocular question, whether a pound of lead or a pound of cork is the heavier, is not fully answered by saying that they are of equal weight ; for the cork is really the heavier, because when balanced in air, bulky cork is more buoyed up than dense lead.

If an ounce of cork and an ounce of lead be counterpoised at opposite ends of a small balance, and then placed under the receiver of an air-pump, the cork will be found to preponderate when the air has been exhausted from the receiver.

As any liquid lighter than water, such as oil or spirit of wine, on being set at liberty under the surface of water, will rise, while any heavier liquid, such as brine, syrup, or sulphuric acid, will sink ;

and in both cases with force proportioned to the difference of specific gravities:—so we find, that in common air, a mass of hydrogen, or of hotter air, ascends, because specifically lighter; while oxygen, carbonic acid gas, or colder air, descends, because specifically heavier. This truth is strikingly exemplified in

442. *The Balloon,*

which is a large thin bag, generally of varnished silk, shaped like a globe or egg, and filled with coal-gas or hydrogen, the latter being about 14½ times lighter than common air. It has to be made so large that the difference between the weight of its volume of hydrogen, or coal-gas, and that of an equal bulk of common air, may enable it to carry aloft the material of which it is constructed, together with the aëronauts and their apparatus. It is in principle like a bladder of oil immersed in water. A globe of 35 feet diameter has a capacity of nearly 22,000 cubic feet. This quantity of common air weighs above 1600 lbs., and the same quantity of hydrogen gas, of easily obtained purity, weighs less than 200 lbs. Such a globe, therefore, would have a buoyancy sufficient to carry up 1400 lbs. of material and load. The standard balloon used in the siege of Paris, 1870, was about fifty feet in diameter, and had a capacity of 70,600 cubic feet. The weight of this volume of air would be about 5000 pounds, and the weight of coal-gas required to fill it (at a specific gravity of 0·40 compared with air) would be 2000 pounds. Hence the difference representing the gross ascending force would be 3000 pounds. The weight of the balloon, net, and car, was about 1000 pounds; thus leaving 2000 pounds available for passengers, dispatches, ballast, and anchoring apparatus. If the same balloon were filled with hydrogen the weight of the gas would be only 350 pounds, and the disposable ascending force would be 3650 pounds.* One of the largest balloons constructed by Mr. Giffard was ninety-three feet in diameter, and had a capacity of 425,000 cubic feet. When filled with hydrogen it took up thirty-two persons at a time to a height of 2000 feet.

The idea of navigating the air so as to imitate the wonderful power of birds, is one of the oldest mechanical ideas of the human mind, and seems to be reflected in the fabled stories of winged gods with which the classic poets abound; but the first successful attempt to realize the idea dates no farther back than the year 1782. It had been observed that soap-bubbles, filled with hydrogen gas, rose rapidly in the air, and it occurred to Montgolfier, a paper-maker near the town of Lyons, to fill thin paper bags with this gas. He did so, and succeeded to a certain extent, only the paper bag allowed the hydrogen to pass through its pores. But he accidentally noticed one day that a fire under the open mouth of a large paper bag, caused it to ascend; and thus, though he mistook the real cause of the phenomenon, the first balloon was invented. He had constructed a huge paper balloon, 33 feet in diameter, and containing 22,000 cubic feet, and lighting a fire under the mouth of it, he astonished the whole town by getting it afloat in the air to a height of some 7000 feet.

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* 'Quarterly Review,' 1875.

Balloons on this principle were called *hot-air* or *fire balloons*, or *Montgolfiers*; and many ascents were made with them in the course of the next few years. The most interesting of all, as being the first in which aëronauts ventured to leave the earth entirely, without being anchored, took place near Passy, on the 21st of November, 1783, when a balloon 76 feet high and 46 feet in diameter appeared to the wondering gaze of all Paris, like a little speck floating along at a height of 3000 feet.

Hydrogen balloons were, however, shortly after introduced, and replaced the fire balloons, as being more commodious and less dangerous, for several serious accidents are recorded from balloons having caught fire when aloft in mid-air.

About 1814 coal-gas was introduced for the purpose of lighting towns. This generally contains a large proportion of hydrogen and light carburetted hydrogen. Its specific gravity is about half of that of air (*i.e.*, 0·4 to 0·5), and it may be readily obtained from gas-works at a moderate cost. Although six or seven times heavier than hydrogen, the difference is compensated by increasing the size of the balloon. Coal-gas is also less liable than hydrogen to diffuse or leak through the covering of the balloon.

443. There are perhaps few sights more surprising and gratifying to the young than that of a balloon sailing high in the air, and bearing human beings to regions far beyond what the soaring eagle has ever reached; while, to the intrepid aëronaut himself, the scene of a world displayed beneath him is unquestionably the grandest, except that of the starry heavens, on which mortal eye has ever been turned. Even wide-spread London, the queen of the cities of the earth, and a little world within itself, when viewed from a great elevation in the sky, becomes but as a dusky patch upon a map, with the Thames winding through it as a silvery line, and the magnificent temples and palaces scattered around, appearing only as darker points standing out of the general mist of buildings, in which four millions of human beings reside.

Mr. Glaisher, who made twenty-eight ascents between 1862 and 1866, in one of which he attained the greatest elevation that man has reached, 37,000 feet, gives the following graphic description of the higher regions of the atmosphere :—

"Above the clouds the balloon occupies the centre of a vast hollow sphere, of which the lower portion is generally cut off by a horizontal plane. This section is in appearance a vast continent, often without intervals or breaks, and separating us completely from the earth. No isolated clouds hover above this plane. We seem to be citizens of the sky, separated from the earth by an impassable barrier. We are free from all apprehension such as may exist when nothing separates us from the earth. We can suppose the laws of gravitation are for a time suspended, and in the upper world to which we seem now to belong, the silence and quiet are so intense that peace and calm seem to reign alone.

"Above our heads rises a noble roof—a vast dome of the deepest blue : to the east may perhaps be seen the tints of a rainbow on the point of vanishing : in the west the sun silvering the edges of broken clouds. Below these light vapours may rise a chain of mountains, the Alps of the sky, rearing themselves one above another, till the highest peaks are coloured by the setting sun. Some of these compact masses look as if ravaged by avalanches, or rent by the irresistible movements of glaciers. Some clouds seem built up of quartz, or even diamonds ; some like immense cones boldly rise upwards ; others resemble pyramids, whose sides are in rough outline. As we descend, the summits of the silvery mountains approach us fast, and appear to ascend towards us. We are already entering deep valleys which seem as if about to swallow us up, but mountains valleys and glaciers all fly upwards. We enter the clouds, and soon see the earth, and in a few minutes the balloon lies helpless and half empty on the ground."*

The first aëronautic expeditions astonished the world, and endless reveries passed through men's minds of important uses to which the new discovery might be applied. But subsequent experience has shown that so long as the problem of steering a balloon, independently of the direction of the wind, remains unsolved, their utility is comparatively limited.

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* 'Quarterly Review,' 1875.

Aëronauts may make the balloon rise farther by throwing out part of the sand-ballast which they carry with them, or may make it descend at any instant by opening a valve at the top so as to allow some of the coal gas to escape, but all plans for guiding the lateral motions of the balloon by rudder, or vanes, or wings have hitherto proved a failure. The average velocity of a balloon is about 25 miles an hour.

A balloon must not be fully distended when leaving the earth, because if only half full at the surface of the earth, it becomes quite full when it has risen three miles and a half, the surrounding aërial pressure at that altitude being diminished to a half. (Art. 435.) In order to allow for this escape of gas the bottom of the balloon tapers to form a pipe. This serves for the inflation, and as it is left open during the ascent, it allows of the escape of gas, as it expands either from diminished pressure or change of temperature. The heat of the sun will cause expansion, and a shower of rain or snow will produce contraction.

444. Perhaps the most successful and interesting experiments in the whole history of ballooning were made during the late Franco-Prussian war. When Paris had been cut off by the German lines from all communication with the rest of France, the employment of balloons for the transport of letters, &c., was organized, and conducted with such wonderful regularity, that during the winter of 1870 the news from the interior of the French capital was never interrupted for more than three or four days together. The balloons were mostly spheres, containing about 2000 cub. metres (about 70,620 English cubic feet) of gas, and were started usually from the Orleans or North Railway Station at nightfall, so as to escape the vigilance of the German troops. As many as sixty-four actually started from Paris (between September 23, 1870, and January 28, 1871), carrying in all 161 passengers, with nine tons of despatches, and something like 3,000,000 letters. Of these fifty-seven were successful in fulfilling their purpose, two having been lost at sea, and five having fallen into the hands of the Germans. Among those who escaped from the beleaguered city by this means were Gambetta and the astronomer Janssen, who took his instruments with him to watch an approaching eclipse of the sun in the south of France.

Baskets of carrier-pigeons were also sent out of Paris, and as many as 50,000 messages were sent into the capital by this means alone, the letters, &c., having been photographed on a microscopic scale, and stuck in pieces of quill attached to the tails of the pigeons.* But several attempts at returning to Paris by aërial means proved a complete failure, on account of the unfavourable direction of the wind. Perhaps the most remarkable of all these siege-balloon voyages was that of M. Rollier, who landed safely in Christiania after a hazardous voyage of fourteen hours across the North Sea.

445. *The ascent of Flame and Smoke*

affords another example of the buoyancy of the atmosphere, for both these are merely hotter and rarefied air pressed up by the colder and heavier.

Flame is produced when the burning substance is already a gas, or contains some ingredient capable, on being heated, of assuming the form of gas. This burns, or combines with the oxygen of the atmosphere, with an intensity of action sufficient to produce a white heat. It is because charcoal and coke have nothing in them thus volatile that they burn without flame, appearing like red-hot stones. The flame of a lamp or candle is merely the oil, wax, or tallow gradually converted into gas by the heat, and allowed to burn as it is disengaged and rises. The same gas obtained by heating the oil, &c., in a retort or close vessel, from which a tube leads to a suitable receptacle or gas-holder, is the common oil-gas used for illumination.

Smoke consists of all the dust and solid particles of carbon which are separated from the fuel without being burned, and which are but minute enough to be carried aloft by the rising current of heated air; all that is visible of smoke is really heavier than air, and soon falls again, as chalk-dust subsides in water. In the receiver of an air-pump, where a candle has been extinguished by exhausting the air, the smoke that streams from the wick after the exhaustion, is seen to fall on the pump-plate, because there is no air present to support it.

446. *Chimneys* quicken the ascent of hot air merely by keeping a column of it together. A column of two feet high rises or is pressed up with twice as much force as a column of one foot, and so for other lengths; just as two or more corks, strung together end to end, rise in water with proportionally greater force than a single cork; or as a long spear of light wood, allowed to ascend perpendicularly from a great depth in water, acquires a velocity which makes it leap for an instant above the surface, while a short piece under the same circumstances rises slowly merely to float. In a chimney where one foot of the column of hot air is one ounce lighter than the same bulk of the external cold air, if the chimney be 100 feet high, the air or smoke in it is propelled upwards with a force of 100 ounces. In all cases, therefore, the *draught*, as it is called, of a chimney-flue, is increased by its length. The following facts are consequences of this truth:—

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* Sixteen folio pages of closely printed matter were thus reduced on the collodion film to a leaf only $\frac{1}{800}$th of the original size. The leaf, or pellicle, weighed three-quarters of a grain, and one pigeon would carry twenty of these leaves rolled up in a quill; the total weight being fifteen grains. They were magnified and read by an optical apparatus.

In low cottages, and in the upper floors of houses, the annoyance of smoky rooms is much more frequent than where chimneys are longer.

If there are two fireplaces in the same room, or in any rooms open to each other, which have chimneys of different lengths, and if the doors and windows be so close that air to supply the two draughts cannot enter by them, the taller will overpower the shorter, and cause it to smoke into the room; just as the long leg of a syphon overcomes the short one, or as a long log of wood, held down in water by a cord passing from it round a pulley at the bottom to a shorter log also floating, will rise, and pull down the shorter log.

A long chimney, for the above reasons, causes a current of air to pass through the fireplace very rapidly, and it has the advantage also of acting more uniformly than any bellows or blowing machine. Hence, for fires of steam-engines and many others, it is the means of blowing generally preferred. The importance of length in a chimney explains the remarkable appearance of our mining districts and manufacturing towns.

When we heap dying embers together, so that the hot air rising from among them becomes a mass or column of considerable altitude, this column has the effect of blowing them gently, and helps to light them up again. A piece of burning paper thrown upon the top of a half-extinguished fire, often makes it glow afresh, by causing a more rapid current of air to pass through it from below, towards the paper.

447. The action or draught of a chimney, which is influenced, as we have seen, by its length, depends also on the **degree**

in which the air in it is heated, because that determines the dilatation, or comparative lightness, which occasions the ascent.

In what are called *open fireplaces*, as used in the sitting-rooms of this kingdom, a large quantity of air directly from the apartment enters the chimney above the fire, and mixes with the hot air from the fire itself. This mixture ascends more slowly than if only the hot air entered directly from the fire. The effect of preventing a part of this colder air from entering is seen when a board or metal plate is placed across the upper part of the fireplace, so as to narrow the entrance :—almost instantly the fire begins to roar, as if blown by a bellows. This plan is often adopted to cure a smoky chimney by increasing the draught, or to blow a fire when a bellows is not at hand. What is called a *register stove* is a somewhat kindred contrivance. It has a flap placed in the throat of the chimney, which serves to widen or contract the passage at pleasure. Being out of sight, it is not well understood or turned to account. This will be more particularly noticed in the chapter on HEAT.

In what are called *close fireplaces*, as those of steam-engines, or brewers' coppers, when the furnace door is shut, no air can enter the chimney but directly through the fire : hence the action of such chimneys is very powerful.

In a room with two fires, or in drawing-rooms communicating with each other, although the chimneys are of equal length, the one over the strongest fire, or which has the chimney best arranged, will act the more strongly ; and if the doors and windows of the apartment be so close as to prevent a sufficient supply of air for both fires, cold air will enter by that chimney which has the weakest action, and the smoke from it will spread into the room. How often is a company annoyed by the smoke of a second drawing-room fire, lighted shortly before their arrival, and which has therefore to contend with the antagonist fire, already in powerful action all the day! While only one fire was lighted the cold chimney was admitting the air to feed it, nearly as an open pane in the window would have done.

448. When the windows and doors of a house fit so closely as not to admit sufficient air for the acting chimneys, part of the supply for these comes down the adjoining chimneys that are not in use. Inattention to this often causes good chimneys to be deemed bad, because whenever a fire is lighted in them, the smoke first formed is thrown back by the descending current of fresh air. Shutting the room door for a few minutes, so as to cut off communication with other *drawing* chimneys in the house, and opening the window a little, will frequently suffice to make the chimney act; and once sufficiently hot, it may continue to act perfectly.

But smoky chimneys are not so easily cured in all cases. When a low house adjoins a lofty house, the wind blowing towards the latter, is obstructed and becomes a gathering or condensation of air against the wall; and if the top of a low chimney be there, the compressed air enters it, and pours downwards. The proximity of high trees or rocks has often a similar effect, to a greater or less extent. In such cases, the only way to remedy the evil is to have the low chimneys made higher. Again, whenever, from the situation of buildings, eddies of winds occur, or unequal pressures, as happens often at street corners, for instance, the neighbouring chimneys do not act regularly. It is proverbial that corner houses, or those at the ends of a row, are smoky houses; and we often see the intended uniformity of architecture in a street destroyed by the lengthening of the chimneys of the houses at the extremities.

When smoke is found descending into a room where there is no fire, its empty chimney is serving as an inlet for air to the house, while the smoke of some neighbouring chimney is passing closely over the top of it. This defect arises chiefly from the chimney-pots in a stack being placed on the same level.

In summer, when fires are not in use, a strong smell of soot may often be perceived in some of the apartments during the day, and may cease at night. The explanation is, that during the day the chimney flue is colder than the external air, and by condensing the air which enters it, causes a downward current through the soot. During the night, again, when the outside air gets colder, the chimney, by retaining the heat absorbed during the day, is hot enough to warm the air in it, and to cause an upward current. These currents, in chimneys left open during the days and nights of summer, are almost as regular as the land and sea breezes of tropical countries. (Art. 449.)

All this shows how important it is to have a clear conception of the motions going on, according to the simple laws of matter, in the invisible air around us. Were such subjects better and more generally understood, many prevalent errors in the arts of life—such as the *warming and ventilating of houses* (see section on HEAT) influencing much the comforts and health of a community, would soon be corrected.

449. *Winds or currents in the atmosphere* are also phenomena in a great measure dependent on the law, that lighter fluids rise in heavier.

If our globe were at rest, and the direct rays of the sun were always beating on the same spot, the air would there be constantly rising like the smoke from a great fire, buoyed up by currents or winds pouring from all directions below towards the central spot. But the earth is constantly turning round before the sun, so that the whole middle region or equatorial belt may be called the sun's place; and there is thus over all the torrid zone a constant rising and over-current of heated air towards the poles, with constant under-currents of colder air from the two poles to take its place. This phenomenon has been going on ever since the sun warmed the earth, producing the steady inferior winds of the northern and southern hemispheres, called *trade-winds*, on which, in most places within thirty degrees of the equator, mariners reckon almost as confidently as on the rising and setting of the sun itself.

The trade-winds, however, although moving from the polar regions towards the equator, do not appear there to blow directly north and south, but the winds appear to blow from the north-east on the one side of the equator, and from the south-east on the other, and the explanation is this:—

The velocity of the earth's surface is greatest at the equator and diminishes towards the poles, because the circle through which any spot is turned in the course of a day, gets less and less towards the poles. Hence the current from the north, starting with the velocity of the earth's surface there, must *drag* as it approaches the equator, which is whirling more rapidly towards the east. The result is that the wind blows not directly from the north but from the north-east. For a similar reason the south current will appear at the tropics as a wind from the south-east. The following illustration bears a very close analogy to this natural phenomenon. If a small globe be made to turn upon its axis set vertically, while a ball or some water is allowed to run from the top of it downwards;—the ball or water will not immediately acquire the whirling motion of the globe, but will trickle downwards, leaving a slanting track upon the globe, and will appear not as a direct line from the axis or pole to the equator, that is from north to south, but as a line falling obliquely.

The trade-winds at their external confines, that is, about 30° on either side of the equator, blow almost due *north-east* and ***south-***

east; but they become more nearly *east* as they approach the central line, because, through friction against the earth's surface, they have at that part mostly acquired the maximum velocity of our globe.

In the upper regions of the atmosphere, again, there must of course be counter-currents distributing the heated air over the globe: these are sometimes denominated the *upper trade-winds*, and for a similar reason they appear to blow from the south-west and north-west. The current which passes from the equator towards our own country (in the northern hemisphere), starts with an eastward velocity of over 1000 miles an hour—a much higher velocity than that which we have at this distance from the equator—and consequently when it reaches us has a higher velocity from west to east than ours, and appears to us to blow from the south-west. By the time it has reached the latitude of the British Isles, this upper trade-wind has got considerably cooler and heavier, so much so as to affect the currents of the air at the sea level; and this explains the prevalence of the south-west wind, and the comparatively mild winters that we in our island home fortunately enjoy. Observations made on the summit of the Peak of Teneriffe show that there is always a strong wind blowing in a direction contrary to that of the trade-wind on the face of the ocean near its base. Those who are sailing from the Cape of Good Hope to St. Helena with a fair trade-wind from the south-east, have often to remark that the sun is hidden for days together, by a stratum of dense clouds passing in the contrary direction high in the atmosphere; which clouds consist of the moisture raised near the equator with the heated air, and becoming condensed again as it approaches the colder regions of the south.

450. Beyond the tropics, where the heating influence of the sun is less, these two great, general, contrary currents of the atmosphere become gradually less distinct. The polar layer, having to cover the widening bulge of the globe towards the equator, breaks into gaps, which the higher layer, being in a corresponding degree compressed as it reaches narrower longitudes, plunges down to fill; and there follow consequently, mixture, contention, and stormy eddies. The winds of the temperate climates are, in consequence of this, described as *variable* winds.

While the sun is beaming directly over a tropical island, it warms the surface of the soil very much more than the surface of the ocean, because his rays penetrate deep into the interior of the latter, and heat the whole mass more uniformly. As a consequence of this, the air over the land is much more heated than that over the sea; thus there is a rapid ascent of hot air over the island during the day, and the result is a delightfully refreshing *sea-breeze*, but for which many tropical islands and coasts would be uninhabitable. Only from actual experience can anyone conceive the delight which the sea-breeze brings after the sultry stagnation which for a time precedes it. The welcome ripple shorewards is first perceived on the surface of the lately smooth or glassy sea; and soon the whole face of the sea is white with little curling waves, among which the graceful canoe, lately asleep on the water, shoots swiftly along.

During the night the direction of the breeze is reversed. The surface of the earth, no longer receiving the sun's rays, parts with its heat very rapidly by radiation upwards, while the sea, which absorbed heat during the day, not on the surface only, but through its mass, continues to give out heat all night. The effect of this is, that the air over the earth becoming colder than that over the sea, sinks down, and spreads out on all sides, producing the *land-breeze* of tropical climates. This wind is often charged with unhealthy exhalations from the marshes and forests, while the sea-breeze is all purity and freshness. Thus a sort of natural respiration on a magnificent scale is kept up continually—an exhaling of noxious air towards the open purifying sea, and an inhaling of pure life-giving breath from over its broad expanse—and all is kept up by the simple natural laws we have been considering.

451. The peculiar distribution of land in Asia produces the notable effect of a sea-breeze of six months, and a land-breeze of six months. The great continent of Asia lies chiefly north of the line, and during its summer, the air over it is so much heated, that there is a constant steady influx from the south—appearing southwest, for the reason already given; and, again, during its winter months, while the sun is over the southern ocean, there is a constant land-breeze from the north—appearing, for a like reason, northeast. These winds are called *Monsoons;* and if their utility to commerce were to be a reason for a name, they also might have been called trade-winds. For in early periods of navigation, they served to the mariner for compass, as well as for moving power; and one voyage outward, and another homeward with the changing monsoons, filled up his year. On the western shores of Africa and America also, the trade-winds are interfered with by the heating of the land; though to a much less extent than in Asia.

452. Even the frightful whirlwinds, known as *Tornadoes*, *Cyclones*, and *Typhoons*, which are so frequent in the West Indies, the Indian Ocean, the Chinese Seas, and the tropical zones generally, and which scatter destruction and desolation in their track, have been found to obey pretty well defined laws, both as regards the rate and the direction of their progress; so that, by the wonderful means of overcoming distance which the electric telegraph affords us, their approach may often be anticipated hours or even days before-hand.

It has been established, from careful and reliable observations, that almost all the cyclones, or whirl-storms of tropical birth, sweep round a centre of barometric depression—in the northern hemisphere, in a direction contrary to the hands of a watch, and with the hands of a watch in the southern. Many storms that come down upon us from the northern or polar regions have also been found to be of a circling or cyclonic character.

Indeed it is a pretty well established fact (see Art. 433) that great atmospheric disturbances generally have a progressive cycloidal motion, the direction of the storm being indicated by that in which the comparative calm, or *centre of disturbance*, is advancing.

Many storms which appear to differ in character from these have been shown to be occasioned by the *interference* of two or more cyclones; and the storms which pass over the British Isles very frequently accord with this explanation. Of course, such interferences produce great complexity and irregularity in the relative weather-indications of a tract of country; there will be great variations in the force and direction in which the wind blows at different places, and the barometer readings and oscillations may be extremely varied and perplexing.

It has been said that "in the daily telegrams from the Azores and Iceland, two, and often three, days' intimation of almost every storm that visits Great Britain could be had;" the former would warn us of the approach of tropical disturbances, and the latter of the descent of polar currents.

We cannot, in the present work, enter further on the details of the laws of storms which modern science has established; for these, reference must be made to works specially devoted to Meteorology. Nor need we point out the incalculable advantages of a knowledge of the principles to which such laws may be referred. The fore-warning of approaching tempests would be one of the most splendid contributions of science to the human race; and, when we consider the surprising predictions which within recent years have been achieved, we may confidently look forward to a time when the ramifications of the telegraph system will keep every corner of our land apprised a day or two beforehand of any important atmospheric changes that are likely to happen.

As an instance of the importance of such information, it has been stated that, but for the timely warning of an approaching storm, our Crimean war might have had a very different issue. While the united French and English fleets were investing Sebastopol, in November, 1854, a telegram was sent from Paris by the French Minister of War to warn the allied fleet that an extremely violent cyclone was raging in the South of France, and from the barometer indications, was calculated to be moving eastwards at a rate which might lead to their experiencing it by a certain time. Punctual almost to an hour, the storm burst with terrific fury on the Crimea; but happily, the gallant navies had been warned in time to enable them to put to sea, and so in all likelihood to escape a most dire destruction.

453. In our tropical colonies, where the great heat and moisture quicken the decomposition of dead organic substances, animal and vegetable, and so produce the poisonous malaria which occasions the fevers and other diseases destructive to Europeans, a means of guarding against the evil is highly important; and such means are suggested by considering the phenomena of land and sea breezes here described.

It is well known that, in approaching Rome across the wide marshy flat called Campagna di Roma, persons who are obliged to pass the night there, at certain seasons of the year, run great risk of catching the fever of the place, which is very often fatal. During the day the danger is not so great. Vera Cruz and its neighbourhood, on the American coast, where passengers from Europe generally disembark on their way to Mexico, and may pass nights, is still more dangerous. Many places on the coast of Africa, such as Sierra Leone, the mouths of the river Niger, and others, are notorious in the same way. Of Asiatic coasts nearly the like has to be said. Rangoon, Bencoolen, and others recall sad histories. When the Dutch first settled in the rich island of Java, they chose, as the site of their future city Batavia, a level, humid plain, where they might conveniently construct canals in the streets, as was practised in their home cities of Amsterdam, Rotterdam, &c. They soon found, however, that mortality from malarial fever was great among those who passed their nights on the low level, while those who had their dwellings on the neighbouring dry heights were safe.

Of all this the explanation simply is, that, though on the damp surface of the earth the decomposition of animal and vegetable substances goes on actively day and night, producing hurtful malaria, yet the earth, warmed by the sun during the day, heats the air in contact with it, and this rising carries away the malaria; while during the night the earth radiates its heat into space and is unable to warm the atmosphere resting on it, so that the heavy malaria accumulates on the surface of the earth as a poisonous layer destructive to those who breathe it.

Precautionary measures, which naturally suggest themselves to one acquainted with the above-mentioned details, are :—

(1.) Not to pass the night in low or dangerous situations.

(2.) If that is unavoidable, then to sleep in the upper rooms of the house. In ague-districts of England persons who sleep near the top of the house often escape.

(3.) To use simple means, such as will be described under the head of VENTILATION, to keep the sleeping-room supplied with purer air from above.

454. *The Pneumatic trough and Gas-holder* of the chemist are contrivances illustrating the buoying up of a lighter fluid by a heavier. It consists of a trough, *a*, of metal, or wood, or porcelain, or glass, of any convenient size (fig. 126). It is nearly filled with water, and has at one end, about an inch under the surface of the water, a shelf, on which jars, *b* and *c*, may rest with the mouth downwards in the water. Any gas is preserved separate from the atmosphere by being confined in one of these jars. The jar being immersed in the water of the trough, will remain full so long as its mouth is kept under the water, owing to the atmospheric pressure. It is then placed with its mouth over an opening in the shelf, so that the gas which is produced or generated in the retort or vessel, *d*, may rise through the opening into the receiver, gradually displacing the water as it rises to the top of the receiver.

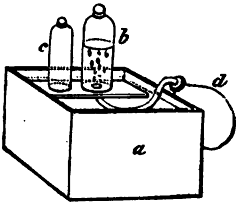

Fig. 126.

455. A *gasometer* or *gas-holder*, such as those enormous sheet-iron reservoirs for the supply of gas to the lamps of our towns and cities, is merely a large cylindrical vessel, as *a* (fig. 127), suspended with its mouth downwards, in a trough or pit of its own shape, *b c*, filled with water. It is counterpoised by weights over pulleys, so that very little force suffices to move it up or down. Gas forced into it through a pipe, *f*, opening under it, causes it to rise or float higher in proportion to the quantity. The gas passes from it again through another pipe, *e*, to the "main," or leading pipe from which all the ramifications lead. It issues with a force proportioned to the downward pressure of the containing vessel, which may be nicely regulated in a variety of ways, and is generally made to equal the action of a column of water two inches in height; that is to say, such, that a pipe issuing from the gas-holder, and dipping into water at its other end, shall allow gas to escape, if immersed less than two inches perpendicularly.

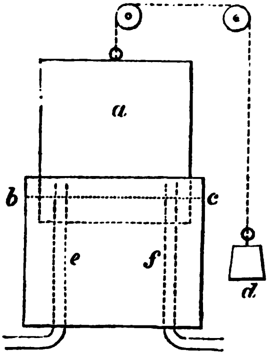

Fig. 127.

THE DIFFUSION OF LIQUIDS AND GASES.

456. The conditions of floating and buoyancy which we have given for both liquids and gases, require modification in certain cases, and these we now proceed to explain.

If liquids of different kinds are put into the same vessel, they will arrange themselves (Art. 329) in the order of their densities, and be separated by perfectly defined horizontal surfaces, ***but only if the liquids are altogether incompatible in their natures, and incapable of permanent mixture, such as oil and water.*** If, however, we take two such liquids as sulphuric acid and water, of which the former has nearly double the density of the latter, and place them in a jar with the acid at the bottom, it will be found that the heavy acid slowly works its way upwards, and that after some time the whole is uniformly acidulated.

This phenomenon of the *diffusion of liquids*, as it is termed, is observed in the case of all liquids capable of permanent mixture, though the time may vary from two or three days to as many weeks before the diffusion is complete; it may be conveniently studied by putting a solution of a coloured salt in the lower part of a tall jar, filling it up with pure water, and then noting the gradual rise of the colour to the upper part, with of course a corresponding weakening of the tint in the lower part.

Another simple and instructive method is to use specific gravity beads (Art. 344) of density greater than water, and less than the salt solutions employed. At first they will all lie on the surface of the lower and heavy layer, but gradually they will separate and float at different depths, and so exhibit the progress of the diffusion.

The diffusion into pure water of solutions of common salt, bichromate of potash, sulphate of copper, sugar candy, gum arabic, treacle, sal ammoniac, and saltpetre, may be mentioned as simple and ready examples within the reach of anyone who wishes to investigate these phenomena.

That the rate of admixture or diffusion depends greatly on the area of contact of the two liquids, may also be proved by the following experiment :—A graduated glass tube, about ten inches long, is filled to one half with distilled water, and upon this alcohol is gently poured until the tube is quite full. A small portion of white wax is now put into the tube. Being heavier than alcohol, and lighter than water, it falls through the liquid until it reaches the surface of the water, on which it floats. As the two liquids become mixed, the wax falls ; but if the tube is not moved, some months may elapse before the wax reaches the bottom.

457. From a very great number of experiments with the solutions above mentioned, Thomas Graham established the following

General laws of liquid diffusion :—

(i.) For solutions of the same salt, the quantity diffused in any time, such as a day or two, increases exactly with the strength or density of the solution ; but for different substances, the diffusiveness is not in proportion to their densities. In every case, however, the *regularity* of the process is greater with weak than with strong solutions.

(ii.) The rate of diffusion increases with increase of temperature. It is found that hydrochloric acid, for example, will diffuse about twice as rapidly at a temperature of 120° F., as at 60° F., or the ordinary temperature of a room. But the same increase of diffusive rate does not obtain for all substances.

(iii.) With dilute solutions, one substance will diffuse into water which contains another substance already in solution, just as if the water were perfectly pure.

(iv.) If solutions of two salts, possessing different degrees of diffusive power, and incapable of chemical union, be mixed and placed at the bottom of a jar containing pure water, the salt which is the more diffusive may be partially separated from the other by its more rapid rise upwards. In this way ordinary alum may be partially decomposed into its two chemical components, sulphate of potassium and sulphate of aluminium. Thus the laws of diffusion are of very great importance to the analytical chemist.

458. The modern or kinetic explanation of the phenomenon is, that the molecules of all bodies are in a state of continual agitation, corresponding to the fact that no body is absolutely devoid of heat-motion. In a solid, these motions are restrained within very narrow limits; in a liquid, they extend through the whole mass, only the continual impacts among the molecules render their translation from place to place comparatively slow; in a gas, however, the molecules being so much farther apart, have no difficulty in intermingling, their motions of translation being limited only by the confining envelope.

In accordance with this theory, is the remarkable fact that diffusion takes place with very much greater rapidity, and in all proportions, between gases of unequal densities. It was, in fact, between gases that the phenomenon was first observed, about a hundred years ago, by the famous Joseph Priestley, to whom we are indebted for the discovery of oxygen.

The diffusion of gases.

459. If a bottle of chlorine gas be connected by a long tube or pipe with a bottle of hydrogen, which is placed at a height above it, the chlorine, though about thirty-six times as heavy as the hydrogen, will gradually rise through the pipe into the upper vessel, while at the same time the light hydrogen will fall down into the lower bottle After a few hours, the green colour of the chlorine will be quite perceptible in the upper bottle, and in course of time the two will be thoroughly mixed, and will never again separate of themselves. By this admixture of the gases, in spite of their relative densities, the contents of each bottle will be rendered explosive. Unless exposed to a strong light or to flame, they will remain as gases mechanically mixed and equally diffused. Under either of the conditions above mentioned they combine with a violent explosion to form an acid compound.

We may select for a safe experiment two gases which do not enter into chemical combination, namely carbonic acid and hydrogen. Carbonic acid is twenty-two times as heavy as hydrogen. If a jar of hydrogen is inverted over a jar of carbonic acid, there will be a rapid diffusion, and in ten minutes the application of flame to the lower jar will show by its combustion that the light hydrogen has descended into the heavy carbonic acid; and if lime water is added to the upper jar it will show, by the production of a white compound (carbonate of lime), that the heavy carbonic acid has ascended into the light hydrogen. These results show a great difference between gases and liquids which have no tendency to combine chemically. Ether and liquid mercury bear nearly the same proportion to each other in density as hydrogen and carbonic acid. They might remain in contact for ever without a particle of one penetrating into the pores of the other.

Laws quite similar to those given for liquids, have been found to hold for gases also, and they can be established with greater rigour, since cohesion does not interfere, as in liquids, to modify the results. Graham established the following

Laws of gaseous diffusion:—

(i.) The rate of diffusion increases as the density of the gas diminishes, and increases at the square of the rate that the density diminishes. Thus hydrogen, which is but one-sixteenth of the density of oxygen, will diffuse four times as fast. And the greater the difference in density of the two gases, the more rapidly will the intermixture proceed.

(ii.) Increase of temperature accelerates their diffusive power by rendering gases specifically lighter; but as different gases, for the same rise of temperature preserve their relative densities, they also preserve their relative diffusive powers.

(iii.) Gases in a mechanical mixture preserve their different degrees of diffusiveness, and may be partially separated by diffusion. Many important analyses may be thus effected.

It is far beyond the power of the finest microscope to trace the motions of the individual molecules of a gas; but the belief in such motions is fully justified by the many careful experiments that have been made on the subject. Graham calculated that the molecules of hydrogen diffuse themselves spontaneously through somewhat more than one foot per minute.

We have diffusion on the large scale in the atmosphere around us, although the process is of course quickened by aërial agitations, in much the same way as in liquid mixtures it is accelerated by stirring. Nitrogen, the lightest gaseous constituent of the atmosphere, is found at the bottom of the deepest mines, while oxygen and carbonic acid, the heavier constituents, are found at the highest elevations which have been reached in balloons. But for this property of diffusion among gases which do not combine chemically on contact, we should find oxygen and carbonic acid confined to the lower strata, and nitrogen to the upper strata of the atmosphere. Gases would float upon each other, according to their specific gravities, like oil on water, and water on mercury. Animal existence on this earth, therefore, depends on the uniformity of the composition of the atmosphere; and this law of spontaneous diffusion and consequent dilution of noxious or unhealthy gases is of the utmost importance in the economy of nature. The gaseous effluvia exhaled by animals and decomposing vegetables, as well as in the products of combustion and putrefaction, would, but for the constant operation of this diffusive power, accumulate in poisonous proportions and speedily destroy animal life.

Osmose of Liquids.

460. Very closely allied to the phenomena we have been describing, are those which occur when liquids or gases are separated by a thin porous division or diaphragm, and which may for liquids be exhibited by the following simple arrangement :—

A funnel-shaped vessel, F D E (fig. 128), has its wider mouth, D E, covered tightly with a piece of thin, moist bladder, and a long tube fitted by means of a cork to its neck, F. If some liquid, such as spirit of wine, or a solution in water of sugar, salt, or sulphate of copper, be then poured into the vessel to fill it, and part of the stem, say as far as A, and F D E, be then immersed, as in the figure, in a dish of pure water, we shall find, after a few hours, that the liquid has risen in the tube, and in the course of a day or two it may rise to the top, and even overflow. A saturated solution of sulphate of copper (blue vitriol) produces this striking result. The explanation is that there has been an influx of water from the outer vessel, and an examination of the water outside will show that there has been a simultaneous efflux of the solution of copper, although at a less rapid rate.

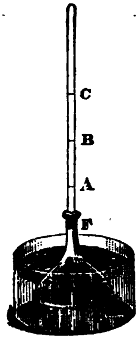

Fig. 128.

To this twofold flow, the names *endosmose* and *exosmose* were given by the French philosopher, Dutrochet, who began the investigation of the phenomena : the first term indicating the influx of the outer liquid, the second the efflux of the inner liquid. For these two names Graham substituted the single name *osmose* or *osmosis*.*

461. The laws of osmotic action are much more complicated than those of simple diffusion, on account of the disturbing effect of adhesion between the membrane and the liquids. Thus it takes place readily through bladder or parchment paper, but not through thin caoutchouc. It seems also most probable that there is more of a chemical than of a purely adhesive action exercised by the material of the membrane ; for in almost every instance of osmose there is more or less chemical decomposition of one or other face of the membrane, and the greater the difference of its chemical affinities for the liquid on each side, the more rapid is the mutual diffusion.

Thus it is found that there is almost no osmotic action between water and gum arabic, or gelatin, or urea, or other neutral organic substances ; but that with water outside and an alkaline solution inside—such as potassic or sodic carbonate—there is a remarkable *endosmotic* effect, while, with dilute acids or solution of acid salts inside, there is a strong *exosmotic* flow : with a dilute acid on one side and an alkaline solution on the other, the conditions for osmose are the most favourable of all. In any case, however, if the porous diaphragm resists the chemical action of both liquids, as for instance if it be a plate of gypsum or caoutchouc, then the osmotic action is inappreciable.

It would thus appear that the *pores* of the diaphragm have less to do with the action than the chemical nature of its material, and, indeed, Graham was led by an extensive series of researches to some remarkable conclusions on this subject, which the scope of the present work will allow us to indicate merely in a general way.

462. All bodies, according to Graham, are in their molecular character either crystalline or else gelatinous—like crystals or like glues—*crystalloids* and *colloids*, as he termed them. In the former class of substances the cohesion appears to be more decided and active in its nature, either freely dissolving in a liquid or firmly knit together as a solid ; in the latter class, the molecular cohesion is less strongly marked, so that their solutions possess a sort of sluggishness and inactivity, with a disinclination either to crystallize or to diffuse.

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* From the Greek, ὠθέω, signifying to push or thrust violently.

Of the latter class are gum, starch, dextrine (the white gum-like mass produced by boiling starch in dilute acids), tannin, gelatin, albumen, caramel (or cane-sugar heated to 420° F.), also bladder, paper, and animal and vegetable tissues generally.

Now it is to the colloidal class that the osmotic diaphragm must in every case belong, and the reason seems to be, that the molecules of the medium enter into a loose or temporary union with the molecules of the solution; and that this, combined with the force of diffusion, allows the crystalline molecules in solution to be handed across, as it were, from the one face of the diaphragm to the other, after which the process of diffusion goes on in the usual way, as if there were no interfering diaphragm.

It is remarkable that even metals, by forming chemical compounds with the liquid on one side of the diaphragm, may be made to traverse it. Thus, let a tube be covered at one end with thin bladder, and a small quantity of a solution of sugar (acetate) of lead poured into it. When the tube is placed on a circular plate of clean zinc, a chemical action by exosmosis is set up. The atoms of zinc traverse the bladder and displace the lead of the solution on the other side of it. This is demonstrated by the metallic lead being deposited in a crystalline form on the bladder inside the tube.

The difference between colloidal and crystalline bodies in rate of diffusion is very marked. For example, hydrochloric acid (or spirit of salt), which is the most diffusible of all substances, will pass through a colloidal diaphragm, such as parchment paper, fifty times more readily than albumen or white of egg; a solution of common salt will diffuse about twenty-one times more readily; and a solution of cane-sugar will diffuse twice as rapidly as caramel, which is the most sluggish of all known bodies.

So great is the difference in diffusibility between the two classes of substances, that osmose affords a valuable chemical means of separating colloids from crystalloids in solution, the operation being termed *dialysis*. A tray or shallow dish, with a bottom of parchment paper, which can be floated on pure water, is called a dialyser; gums, albumen, caramel, &c., can by means of the dialyser be easily purified from any salts with which they may be mixed, while it would be almost impossible to purify them in any other way.

463. Organic substances generally, excepting those which are crystalline, belong to the class of colloids; the mineral poisons, such as arsenic, are crystalline; hence, to detect a poison in the stomach or intestines of a dead body, the modern analyst places the suspected liquid in a dialyser, and if there is any appreciable quantity of mineral poison, it will be found after a few hours to have passed completely through the parchment paper into the pure water outside, where its presence may be detected by the ordinary chemical tests.

The form of apparatus used for this purpose is represented in fig. 129. A is a glass beaker containing water up to the level, B B, and C is the dialyser, a conical glass vessel open at the narrow top, and closed at the bottom by thin gutskin or parchment paper, D D. The liquid for dialysis is indicated by shadowed lines in the dialyser, which is suspended from a glass rod at the proper level. By this apparatus such a poison as strychnia, if the solution is made acid, will traverse the membrane and be dissolved in the water, leaving in the dialyser mucus, blood, food, and other viscid substances with which the poison may have been mixed. It may then be obtained by evaporation in a state fitted for testing.

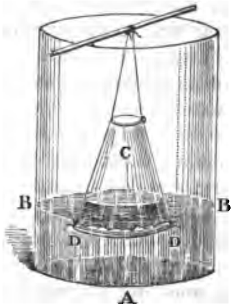

Fig. 129.

The importance of the part played by this process of diffusion in the animal and vegetable kingdom is not yet fully understood. The various tissues and internal organs of animals and plants are constructed of plastic, colloidal materials, through which diffusible liquids circulate, and there can be no doubt that the various processes of absorption, nutrition, and secretion are most intimately connected with liquid diffusion and osmosis.

Osmose of gases.

464. Gases behave in a manner precisely analogous to that in which liquids behave when separated by a porous diaphragm. Thus, if a thin india-rubber or collodion balloon be distended with common air, and put inside a jar filled with hydrogen, the hydrogen will slowly make its way into the balloon, while the air in the balloon will at the same time pass out, but more slowly, so that the balloon will become more and more distended, until at last it may even burst. Conversely, if a jar filled with hydrogen have its mouth closed by a thin sheet of india-rubber, or moist bladder, and be left to stand in the open air, the inclosed hydrogen will escape more rapidly than the air enters, and in consequence the elastic covering will in the course of a few days become concave or hollow. If a soap-bubble be blown with carbonic acid gas, the gas will escape through the soapy film by a mode of osmotic action, similar to that described in the preceding article on the osmose of liquids. The carbonic acid enters into a temporary chemical union with the molecules of the film becoming liquid for a time, and making their way to the exterior surface of the bubble, where they escape by evaporation, the soapy film being a colloidal substance. Another substance which Graham considered to behave in the same way is caoutchouc, or india-rubber. Its molecules seem to have the disposition or power to unite in a loose chemical way with gases, making them semi-liquid for the time, and so conducting them from one face to another with great readiness.

Vapours are subject to the same osmotic force as gases. If a small quantity of prussic acid is placed in a glass vessel, tightly secured with a thin layer of bladder or gutskin, it will be found by applying chemical tests to the outside of the bladder that the vapour speedily traverses its pores. In this way the acid may be diminished in strength, or the whole of it may disappear. If a mixture of alcohol and water is thus exposed in a bladder, it is found that the watery vapour penetrates the pores of the bladder and escapes, but the alcohol remains and becomes stronger. This liquid has no tendency to enter into any combination with the albuminous tissue of the bladder.

465. It is probable, however, that the pore-surfaces of the membrane exercise a sort of semi-chemical attractive force, different perhaps for different gases, and that this serves to bring the gases face to face, after which diffusion will complete the intermixture. Although, then, the solid parts of the membrane or diaphragm would retard the process of diffusion, this obstruction is compensated by the new force of adhesion brought into play from the great extent of porous surface. This view is supported by the fact that the diffusion of gases takes place through a thin cake of graphite or compressed plumbago, or of plaster of Paris, almost as readily as if nothing were interposed. This may be shown by taking a glass phial with a long narrow body, cutting off the bottom (as may easily be done with a diamond or with a poker heated red-hot), and plugging up the end, A, with a thin plate of dry plaster

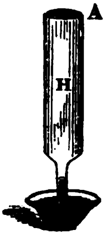

Fig. 130.

of Paris (fig. 130). On filling the bottle with hydrogen and immersing its mouth in water, we shall find the water rise in the neck of the phial, showing that the hydrogen has escaped, air slowly enters and replaces the hydrogen, and the water falls in the neck again to its former level.

466. A very striking method of studying the phenomenon of diffusion of gases is given by Dr. Miller in his 'Elements of Chemistry.' If a porous cylinder of clay, such as is commonly used for galvanic batteries (see *Electricity*), be cemented on the end of a long glass tube, and the other end of the tube immersed in a basin of water, W, (as in fig. 131), and a bell-jar or receiver, R, be placed over the porous jar, when hydrogen gas, or even common coal gas, is allowed to pass up under the mouth of the receiver, R, it diffuses so rapidly into the porous pot, P, that it forces air bubbles out through the water at the lower end in W. If, after allowing this to go on for some time, we remove the cover, R, the hydrogen which has entered will escape so rapidly that the water will rise in the tube to a considerable height.

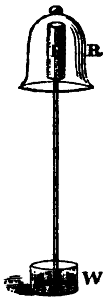

Fig. 131.

Mr. Ansell has constructed on these principles an ingenious piece of apparatus for detecting the presence of an explosive mixture of fire-damp and air in the galleries of coal mines. Various forms have been given by Mr. Ansell to this detector apparatus. The most simple consists of a ball of thin caoutchouc filled with air and fixed upon a stand under a lever which slightly presses the upper surface of the ball. If from any cause the lever should be raised, a spring is liberated which sets a bell in vibration, or brings an electro-magnetic alarum into operation. If the apparatus is placed where fire-damp exists to a dangerous extent the light carburetted hydrogen passes through the pores of the caoutchouc ball, and as the air in the latter passes outwards at a much lower rate, the ball soon distends, exerting sufficient pressure on the lever to bring into action the signalling arrangement, which, if electric, may be placed at any convenient distance from the fire-damp detector, being connected with the lever by means of connecting wires. The principles on which the apparatus is constructed are sound and scientific, but the delicacy of its construction has hitherto proved a bar to its general employment.

467. For the discussion of other phenomena of gaseous diffusion analogous to these—such as the fact that different gases pass through similar capillary tubes at different rates, or that hydrogen gas passes through certain metals when heated red-hot—reference must be made to special researches on the subject, such as those of Graham, published in the 'Philosophical Transactions of the Royal Society.' To the chemist as well as to the physicist they are of the greatest interest, and probably at some future day these various allied phenomena may be all united under one common simple law, the expression of which is not yet apparent.

Perfect vacua.

468. In recent years the perfection of vacuum-making instruments has occupied a good deal of the attention of physicists. Various mechanical improvements have been made upon the common air-pump, described in Art. 402, but without any change in the essential principle of its construction.

One of the most important of such modern improvements is a double-acting single-barrelled air-pump, invented by M. Bianchi, of Paris. The principle of its action may be easily explained. The exhausting cylinder is connected at top and bottom with the passage or pipe leading to the receiver, the openings being closed by conical plugs, or valves, at the ends of a metal rod, which slides air-tight and stiffly through the piston. When the piston moves down, the bottom valve is closed, and connection with the receiver opened by the upper plug or valve; the air between the piston and the bottom being pressed out through a spring-valve in the piston, which closes the end of the hollow piston-rod. When the piston moves up, the upper valve is now closed and communication with the receiver made through the lower valve; while at the same time the air which had passed into the cylinder from the receiver during the down-stroke, is now pressed to the outside through a second spring-valve in the top of the cylinder.

Every up and down stroke is consequently an exhausting one, and the operation of making an ordinarily good vacuum is very much shortened.

The up and down strokes are also produced by continuous rotation of a toothed wheel, the pump-cylinder oscillating from side to side with the motions of the crank. The whole is of cast-iron, and for rapid exhaustion on a large scale, this pump is well adapted.

Even the most perfect of such solid-piston air-pumps gives but a very limited exhaustion. Ordinarily the air cannot be reduced by such means to more than $\frac{1}{300}$ of its usual density, that is, reduced to support a column of mercury $\frac{1}{10}$ of an inch in height.

The limiting causes are, leakage at the different valves and joints of the apparatus, the evaporation of the lubricating oil into the newly formed vacuum, and the want of perfect accuracy in the fitting of the pistons to the ends of the cylinder.

469. Mercury has been suggested as meeting these defects, being a dry, frictionless, perfectly fitting, or self-adjusting piston.

The celebrated Geissler, of Bonn, in making his vacuum tubes for electrical purposes (*see* ELECTRICITY), employed a simple mercurial pump, by which he carried the exhaustion to a very high degree. His apparatus consisted essentially of a long barometric tube, with a wide bulb at the top, and provided with glass stop-cocks at top and bottom. The tube is filled by pouring in mercury from the top; after it is quite full the stop-cock is turned and communication cut off with the air, but opened with the receiver, or vessel to be exhausted. On turning the lower stop-cock, a barometric, or torricellian vacuum, would be formed. Into this the air from the receiver expands, and so is rarified. The connection between the receiver and the tube is now cut off, the exhausted air got rid of, and the operation repeated, till the required degree of exhaustion is obtained.

470. A modification and simplification of this is known as Sprengel's pump.* Fig. 132 will give an idea of it. R, is a globular vessel to be exhausted; B and C are two india-rubber connecting tubes, which can be closed by spring clamps and opened at will. Mercury is poured into the glass funnel, F, and if the clamps, B and C, be open, the air in the tube, C M, as well as in the connected receiver, R, is swept out by the falling mercury, until at length the mercury will attain in the tube, M C, a height very nearly equal to the height of the barometer, and the mercury from the funnel in falling down will make a sharp metallic ring. The full tube should not be over $\frac{1}{10}$ of an inch in diameter, and should be six feet long. When every precaution as to the india-rubber connections is taken, air may be reduced

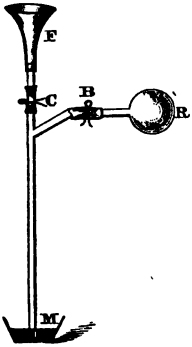

Fig. 132.

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* See 'Journal of Chemical Society' for 1865.

by this arrangement to one-millionth of its ordinary density. The whole labour consists in raising the mercury from the lower vessel, M, to the upper F.

Some chemical methods have been proposed for carrying the creation of a vacuum to its furthest limit. One of the most recent and interesting of such methods is that due to Professors Tait and Dewar, which takes advantage of the power that charcoal has of condensing or attracting gases into its pores. While exhaustion by means of an ordinary pump is going on, the charcoal is kept heated; and after the exhaustion has been carried to the furthest extreme that the pump will allow, the vessel is closed and the charcoal allowed to complete the vacuum by condensing the residue of air which is still present. By this means an almost perfect vacuum was attained.*

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* See 'Nature,' July, 1875.

SECTION IV.—ACOUSTICS; OR, THE PHENOMENA OF SOUND AND HEARING.

ANALYSIS OF THE SECTION.

SOUND *is heard when some sudden shock or impulse occurs in any body having communication, through the air or otherwise, with the ear.*

The impulse which causes the sensation of sound SPREADS *or is propagated in all bodies, somewhat as a wave spreads in water, with decreasing strength as the distance increases, but with a velocity nearly uniform for each substance, and which in air is about* 1120 *feet per second.*

Sound is REFLECTED *from smooth surfaces, and hence arise many curious and pleasing effects called* ECHOES, *&c.*

If such impulses are repeated at very short intervals, the ear cannot attend to them separately, but hears them as a CONTINUOUS SOUND. *This is* UNIFORM, *or what is called a* TONE, *if the impulses be similar and at equal intervals, and it is called* GRAVE *or* SHARP, *according as these are few or many in a given time. All continued sound is but a repetition of impulses.*

When the number of impulses in a given time producing some uniform continued sound has a simple relation, as of double, triple, quadruple, half, third, fourth, &c., to the number producing some other such sound which is heard either simultaneously, or a little before or after, the ear in general is pleasingly affected by the sounds; and they are said to have a MUSICAL RELATION *to each other, or to be* ACCORDANT, *while others not so agreeing are termed* DISCORDANT.

The structure of the EAR *illustrates and is illustrated by the laws of sound.*

471. Early inquirers into nature had remarked that in most instances of noise or sound there was present a shock or trembling of the sounding body, often visible, but sometimes discoverable only by other means; it was visible, for instance, in the string of a harp, in the reed of an hautboy, in the prongs of a tuning-fork, and in the lip of a bell. It was reserved for the moderns to discover that the animal organ called the ear is a structure of wondrously delicate parts adapted to receive impressions from the concussions or tremblings of things around; and that sounds in all their varieties are merely such motions, affecting the ear through the air, or other medium reaching from the trembling body to this organ.

Because all bodies around us are immersed, in common with ourselves, in the ocean of air which envelopes the earth, we are much more frequently warned of these shocks and tremblings by their effect on the air than in any other way; hence the early conclusion that air was necessary to sound, and hence, in part, the reason why the study of sound was formerly included in that of *Pneumatics.** It is now known, however, that all bodies are more or less fitted to convey these tremblings, and that air in many cases is neither the quickest nor the best conductor. As a highly elastic fluid the air is, however, admirably adapted to transmit the pulsations of sonorous bodies by its own undulatory motion in all directions with equal velocity (Peschel).

472. "*Sound is a shock or impulse transmitted to the ear, through the air usually, from some body which is itself in motion.*"

A single impulse, such as the blow of a hammer, the clap of hands, the crack of a whip, a pistol-shot, an explosion, the near thunder-clap, transmits in all directions around its source, a pulse or motion of the air-particles, which reveals itself to the mind as a more or less violent tap on the sensitive membrane of the ear. The sound is generally a series of successive shocks or tappings more or less regular, the sounding cause being itself in a state of rapid trembling.

The conditions required for the production of sound are—1, freedom of vibration in the body; and, 2, contact with such elastic matter as will readily conduct it. If a large glass funnel is suspended and the rim struck, a musical sound lasting for some seconds is produced. That the funnel is undergoing vibration may be proved by touching it with the finger. The vibrations may be felt, but are instantly stopped by contact, and the sound ceases. The dampers in pianofortes and other musical instruments act on this principle. Wool, hair, feathers, and substances of a similar kind do not possess the property of conducting sound, and consequently arrest it when brought into contact with a vibrating body.

That air or some medium is necessary for the transmission of sound is readily proved; for an alarum-bell inclosed in the receiver of an air-pump is heard less and less distinctly as the air is withdrawn, and in a perfect vacuum it is not heard at all. Even the blow of a hammer, in a vacuum, is not heard if care is taken to prevent the shock from being communicated through neighbouring bodies. In the thin air about a lofty mountain-top, the report of a pistol is not nearly so loud as at the base of the mountain, and human voices are remarkably weakened. On the other hand, in the condensed atmosphere of a diving-bell a whisper is loud. Thus if the craters of volcanoes were first discovered in the moon, some persons are said to have watched during the stillness of night to hear the thunder there,—not reflecting that there is no sound-conveying medium extending from the moon to the earth.

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* The phenomena connected with this subject are now so numerous that they are arranged as a whole under a distinct branch of Physics called ACOUSTICS, from the Greek word, ἀκούω, I hear.

The vibrations which produce sound may not only be felt but made visible to the eye. Thus if the wetted finger is drawn over the edge of an ordinary finger-glass containing water, a musical sound is produced by the vibratory motion imparted to the glass, and a ripple is visible on the surface of the water corresponding to each part of the glass set in vibration. This ripple may be seen to follow the finger in its course. (See Art. 542.)

473. Certain metals and alloys, owing to their elasticity, are readily set in vibration, and by communicating this motion to the air, cause sounds. Copper and silver are remarkable in this respect, while lead and tin are much less sonorous. An alloy, known as *bell metal*, consisting of about 78 of copper and 22 of tin is admirably adapted to receive and transmit vibrations. The alloy of which the Chinese *gong* is formed, has a similar composition. Steel, a compound of iron and carbon, is hard, highly elastic, and enters readily into vibration, producing musical sounds. In the form of wire this is the material selected in the manufacture of the piano-forte and other stringed instruments.*

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* The production of musical sounds by the vibration of glass is well known, but their production from such substances as rough flints, such as are found in chalk, is a novelty. A M. Bandre has been lately exhibiting in London what he calls a *geological piano*. It consists of twenty-eight flints—long in proportion to their width,—the longest, producing the graver sounds, being eighteen inches in length, and the shortest five or six inches. They are suspended by strings across a kind of sounding board. They have been selected so as to have a proper musical relation to each other. On striking the flints sharply with a piece of hard porphyry, a rich musical sound is emitted. Several airs were successfully played on these stones by M. Bandre.

474. The *form* of a solid materuenially inflces its power of vibrating and producing sound. A metallic ball or sphere is not fitted for this purpose. The spherical shape, being equal in all directions, prevents any free vibration of its parts. If the ball is divided, and the edge of one of the hemispheres be struck, a loud, clear, and distinct sound is produced. In this form the metal acquires the greatest elasticity, and allows of free vibration. Hence the bells used for clocks and musical purposes are generally of a hemispherical form. The ordinary railway alarum is constructed of two hemispheres which can be brought close together or separated. The high-pressure steam discharged from the boiler into these hemispheres sets the upper one in vibration, and produces a sound which is intensely shrill or grave according to the degree of separation. On a still night this sound may be heard for many miles, and the varying tones serve as telegraphic signals on the line.

Any cup-shaped vessel of elastic metal, very readily takes on a vibration, during which its form is constantly changing from the perfect round to the oval, and conversely; there is consequently repeated percussion of the air, and a continued sound. A bell may be made of any elastic substance, such as metal, glass, porcelain, or even of hard wood. The *Chinese gong* is shaped like the lid of a large round band-box, having a rim of three or four inches in depth. When suspended by the rim and struck with a wooden mallet with a gradually increasing force, from the circumference to the centre, it enters into general vibration, and emits sounds of surprising intensity. The *drum* has a tense elastic membrane on which the blows of the drum-stick are received: its tone ceases quickly because the motion of so broad a surface is much resisted by the air. In the flute, flageolet, common organ-pipes, &c., the air is forced through narrow passages, and is divided by sharp edges, in such a way as to suffer repeated but perfectly regular condensations or interruptions sufficient to affect the ear; and hence the endless variety of pleasing continued sounds which these instruments are known to produce.

475. *Sound waves.*—When a sonorous body is set in vibration it produces a progressive motion in the air, to which the term undulation is applied. These undulations are usually called *waves of sound.* As a rule we believe the sonorous body to be in the direction in which the ear is affected by these undulations, and this belief is the basis of many remarkable aural illusions.

This sonorous aërial tremor, pulse, or *wave,* as it is called, is not an actual projection or shooting of the particles of the air by the sounding body, but is analogous to the spreading of the circular liquid waves seen when a stone is dropped into a pool of water, of which the surface is perfectly smooth.*

As it has been already stated in Art. 358, we are apt to fancy that the advance of ocean waves is an onward movement of the water; whereas, if we watch the motions of a piece of wood floating on their surface, it will be perceived that the movement of the water is up and down merely, while the *form*, *shape*, or *disposition* of the surface layer is all that is really progressive. We are familiar with the same sort of wave-transmission in the shaking of a rope, or of a chain, or of a long strip of carpeting. There is, of course, no onward movement of the links of the chain or rope, but each merely makes an *oscillation*, *excursion*, or *vibration* up and down, so that the successive links occupy in turn the crest of the wave. Thus, if the end link, A, of a chain, A D (fig. 133), be sharply moved to H, then down to K, then back again to A, a certain length, A B C, of the chain will, during the up and down movement of A, be thrown into the form of a wave, as represented here. When A is brought to rest the successive links will, one by one, follow it and come to their first position,

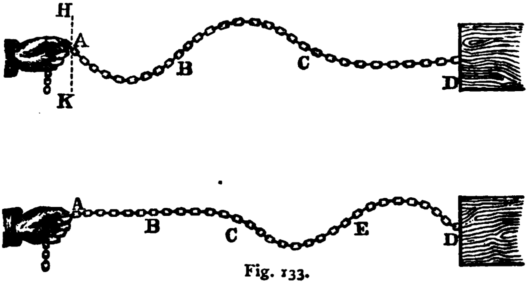

Fig. 133.

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* Under the horizontal condition of liquids, the circular waves are necessarily superficial, but in gases like the atmosphere, the vibrations assume the form of concentric spheres. Sound is heard in all directions equidistant from the centre which is the seat of the vibratory impulse.

When stones are dropped into smooth water at a short distance from each other, it will be found that the concentric undulations produced traverse each other without destroying the circularity of the undulations produced by each. So with sounds, the vibrations of two concentric spheres will traverse without neutralizing or destroying each other.

while the motion will pass on from C to the remaining links of the chain, each making a vibration up and down similar to H K, the excursion of the first link, A. The lower of the two figures in the diagram shows the wave motion just arrived at D.

The distance A C or C D is called a *wave-length*, and the length H K, or the extent of the excursion made by any link in the chain, is called the *amplitude* of the vibration. It is obvious that the time of one vibration is the same as the time taken by the disturbance to advance through one wave-length. Two links in exactly the same situation relatively to their natural or neutral position of rest are said to be in the same *phase* of vibration.

476. Waves may be of different lengths for the same amplitude of vibration, as shown in *I*, *II*, *III*, fig. 134; in *I*, there is one wave represented; in *II*, there are two waves in the same space, each therefore being only half the length of the former; and in *III*, there are three in the space of the single wave in *I*; but in all, the amplitude or vertical depth between crest and hollow, is the same. The dotted line in *I* shows again a wave of the same length as A B C, but of greater amplitude.

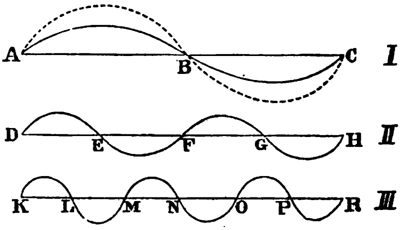

Fig. 134.

477. But the aërial vibrations which constitute sound are of a different character from these by the very nature of the case. There is no cohesion to link the air-particles together, so that *lateral* motions of any one particle, would not be passed on to the next; only *forward* impulses, impacts, or pushes can be communicated. The relation of the two cases or kinds of vibration may

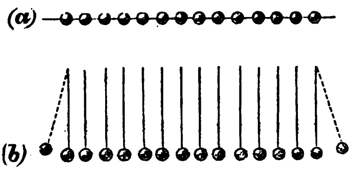

Fig. 135.

be illustrated by a number of similar balls or beads. These may be arranged, as in (*a*) (fig. 135), all on one string, or, as in (*b*), hanging by separate strings, so as just to meet, but be independent of each other.

In (*a*) a side motion of the first ball starts a wave similar to that in the links of the chain already described. In (*b*) a *push* or impact of the first ball passes on to the other balls; and though the internal pushes are too rapid to be seen, the last ball moves away, showing that the push has really been transmitted.

In the latter case, which is precisely analogous to that of sonorous aërial vibration, the first ball, in pushing against the second, does not transfer its motion instantaneously, but only gradually; so that, before it has passed to the extreme right, three, four, or more of the balls may have felt the push. Returning, in virtue of its elasticity, like a pendulum, towards its original position, the push meantime passes on; and by the time the first ball has come back to its starting place on the extreme left, a whole series of balls will have been disturbed, the first half of the series having an onward, pushing, or compressing motion, the last half a backward, relaxing, or expanding movement.

The air is a collection of minute particles—far more elastic than any ivory or glass balls—which, in a way similar to the balls we have been considering, will transmit the impulses of a vibratory body in a succession of waves or pulses, each consisting of a pulse of condensation and a pulse of rarefaction. The motions of the individual particles of air are very minute, but the transmission of the shock is so rapid that during this small vibration of an air particle, a wave of some feet may have been set up.

If the vibrating body be in the open air, the impulses spread equally on all sides around, and consequently diminish in intensity with the increased quantity of air affected, until finally the tremor may be too feeble to announce its presence to the ear; but if a column of air be inclosed in a tube or pipe, the pulsations will be passed on almost without loss, very much as the mechanical impact was transmitted along the row of balls.

478. A striking illustration of the power of air to transmit such mechanical impulses is seen in the explosion of a powder magazine. The shock is sufficient to break windows and shatter houses at a considerable distance from the spot.

In the explosion of five tons of gunpowder which took place in October, 1874, on the Regent's Canal, traversing the Regent's Park, the injury done by concussion and vibration was of enormous extent. It was reported that more than a thousand houses in the north-west of London had been damaged more or less in this catastrophe. Major Majendie states that the area of structural damage to houses extended to a distance of four hundred yards from the seat of explosion under the Canal bridge, and the area of damage to window-frames, sashes, ceilings, and doors extended to six hundred yards. The area of broken windows reached from three-quarters of a mile to one mile, and the area within which the shock or sound is known from reliable evidence to have been sensible, was fifteen miles (Waltham Abbey). The concussion at two and three miles distance was very violent, and one death, produced by the shock and alarm, occurred at two miles (Holloway).*

In those cases in which the windows were open, the glass for the most part was not broken.

All sounds of great intensity, such as those of thunder and the discharge of heavy artillery, produce sonorous waves of such force as to break and destroy glass and other brittle objects. This is simply the result of a sudden and violent concussion of the air.

On the other hand, the aërial concussions which accompany feeble sounds may be revealed and beautifully illustrated by their action on flame :—

Effect of vibrations on flames—Sensitive flames.

479. Flame, or the combustion of light and highly volatile matter in a visible form, is admirably adapted to show the existence of feeble currents of air, and it has proved equally serviceable in establishing the existence of vibratory movements of the air as the result of sound when all other methods have failed.

When coal gas is burnt out of a small orifice, V shaped and under sufficient pressure, a tapering flame about fifteen inches in length is obtained. Mr. Barrett found that the shape and character of the flame underwent some remarkable changes when sounds were produced near it. On clapping the hands, or tapping the table, the tall quivering flame shrank down nearly half its height, spread out laterally into a wider or fish-tail flame, and gave an increased amount of light. On the cessation of the sound, the flame again rose to its original height. He was thus able to fire gunpowder or gun-cotton by producing sound at a distance from the flame. The sound produced by the gentlest tap, and not mere loudness, the chinking of money, the shaking of a bunch of keys, the creaking of boots, the crackling of a fire, the dropping of a cinder, the ticking of a watch, and even the splashing of a rain-drop—all of these sounds startled or convulsed the flame, and the crumpling of tracing-paper or the rumpling of a silk dress, caused it, as Mr. Barrett describes, to become frantic with commotion. We have therefore in this kind of flame a wonderfully delicate test of the vibratory motions in the air which produce sound.

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* Report on the Explosion of Gunpowder in the Regent's Park, 1875, p. 10.

480. These remarkable changes in the flame are due simply to the effect of sonorous vibrations, and not to the concussion of the displaced air which attends the original production of the sound. A stroke on the C above the treble of the piano produced just the same effect as the clapping of the hands. It is, in fact, as Mr. Barrett has stated, the product of translated *motion*, and not of translated *matter*. It is the result of those undulations of the air by which sound is propagated. The facts, too, illustrate the velocity with which sound is propagated, for the movement of the flame is simultaneous with the hearing of the sound, whether near or distant, so long as it can be heard.

If a man whistles near such a flame it instantly responds, and is lowered as described. If he leaves the room, and shuts the doors, the flame still responds to the whistle outside, in spite of this obstacle to the passage of the vibrations. This shows how small an amount of vibratory motion in the atmosphere may be rendered evident by a sensitive flame. At thirty or forty feet distance, a sensible effect was produced by sound on the flame, and considering that the vibratory movements are inversely proportional to the square of the distance, the amount of motion by which it was affected must have been infinitesimally small.

481. This kind of flame is not equally sensitive to all sounds. Thus the bass notes of a pianoforte did not disturb it, but as the high notes were approached, the flame became uneasy and its shape was changed. In reference to speech, it was found to be remarkably sensitive to sibilants; thus such words as hiss, hush, and brush caused it to be instantly lowered; and, according to Mr. Barrett, even "if you go away and out of sight the flame will shiver all over every time you utter the obnoxious sibilant." It is only the high notes of a violin which affect it; but it dances to the music in perfect time when a tune is played to it on any musical instrument.

In an experiment performed at the Royal Institution, Professor Tyndall caused the flame to dance to the tune played by a musical box. When spoken to, or verses were recited near it, the flame underwent a variety of changes, moving up and down, widening and contracting itself according to the nature of the sounds.

The remarkable effects produced on flame by those vibratory movements of the air on which sound depends, have not yet received a satisfactory explanation. There is a mystery about them which no philosopher has yet been able to fathom. It is impossible to witness them without a profound feeling of wonder. The results are more like the effects attributed to magic than those obtained by philosophical research. As Mr. Barrett remarks, "We are surrounded by wonders and enveloped in mystery, and at present science can do little more than reveal these wonders, classify these mysterious facts, and awaken a right and intelligent appreciation of them.

482. *Sounds from currents of air.*—The action of the Æolian harp, which will be described hereafter, depends on a current of air setting in vibration a number of harp-strings stretched over a hollow box. When a strong current of air passes through the meshes of a fine wire-blind, a musical sound results, not directly from the current, but from the vibrations communicated by the metallic wires to the surrounding air. In like manner strong currents of air passing through chinks in walls or wooden partitions, crevices of doors, or key-holes, may produce sounds rising and falling with the force of the currents. So that the current can set some solid material in vibration, a sound is produced, sometimes shrill, sometimes grave or moaning, and calculated to give rise to superstitious fears when the cause is not understood. To this class of phenomena may be added the howling of the wind in disused chimneys, or in the bays and recesses of old buildings.

It is probable that the sounds heard in ancient times to issue from the colossal statue on the plain of Thebes, known as the *Vocal Memnon,* were due to a similar cause—the passage of a current of air through the crevices of a sonorous stone. There can be no doubt from concurrent testimony that, at or about sunrise there issued from this vast monolith in ancient times a sound which was said to resemble that of the breaking of a harp-string. It was set down to the juggling of the priests, but there was nothing to support this view. The statue had been injured by an earthquake (27 B.C.) and repaired in five blocks from the middle upwards. It was after this restoration that the sounds were heard to proceed from it, but only occasionally in the early morning. It is highly probable, as Sir D. Brewster suggested, that the sudden change of temperature which took place at this time produced strong currents of air through the crevices of a sonorous stone. This explains why the phenomenon could not be uniform or constant, but dependent on the varying conditions of temperature and season.*

The concave, undulating, and perfectly smooth internal surface of many sea-shells fits them to catch, mix, and return the pulses of sounds that happen to reach them, so as to produce that curious murmuring resonance from within, which closely resembles the sound of a distant ocean, and which popular fancy ascribes to their billowy ocean home. The contact of the mouth of the shell with the warm skin of the ear expands the air and causes a current to be set up. This produces a sound reverberated by the spiral form of the interior.

"*These tremors or undulations, which cause the sensation of sound, may also be conveyed by liquids, or even solids.*"

483. Although material particles in the form of liquid or solid are so much nearer to each other than in the form of air, we still have many proofs (Art. 31) that they are not in absolute contact, and we therefore see the reason why the impulses producing sound, should be transmitted through a liquid or solid in the same manner as through air, and why in these cases, by reason of the greater proximity of the particles, as well as by their superior elasticity, they should spread more quickly and forcibly than in air.

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* In the year 194 this statue was visited by the Emperor Septimius Severus. It remained absolutely dumb. No sound could be heard. The Emperor ordered it to be repaired, and in this work the ancient crevices were, no doubt, filled up, for, since that date, no sounds like those described by the ancients have been heard to proceed from this representative of 3275 years! An English traveller, Sir A. Smith, who visited the statue about fifty years since, states that he heard sounds issue in the early morning, not from the statue, but from the pedestal. Subsequent travellers have not confirmed this statement. That sounds may issue from the effects of the expansion of air in rocks and caverns is quite consistent with experience. Humboldt made some observations on the rocks of the Oronooko which confirm this view. These sounds were heard to issue from the rocks just before sunrise. The natives attributed them to witchcraft.

Instances of sound carried by air have been given already: as further examples, we may cite the cases of what are called *sympathetic sounds.* Most elastic solids, when of certain shapes, being sonorous, that is to say being fitted to tremble when struck, with a certain frequency of oscillation depending on their weight and shape, if the air around them be made to tremble by any cause, with the velocity which they are fitted to take on or produce, they immediately begin to tremble in unison with the air; and their motion or sound may continue after the original cause of it has ceased. Thus almost any clear tone produced near a pianoforte whose dampers are raised, finds a responsive string, and if bits of paper are placed upon the strings generally, those falling on the strings which in turn can vibrate in unison or as octaves to the sounding body are soon shaken off, while the others remain. A harp or guitar, in a room with loud-talking company, is often mingling a note with their conversation. A wine-glass or goblet may be caused to tremble (and if on a table at all inclined, even to fall) by a person sounding, on a violoncello near it, the note accordant to its own.

484. Sounding bodies vibrate much more quickly, or have sharper tones, if placed in light hydrogen, than in common air, and more quickly in common air than in any of the heavier gases, because the lighter the surrounding fluid, the less is the resistance to a body moving in it.

If a bell-glass, suspended, is filled with hydrogen by displacement, and a bell struck violently is suddenly introduced into the gas from below, the sound is almost lost. On bringing it into the air, the clear ringing sound is again perceived, showing how much depends on the density of the aërial medium. If a bell struck in air is plunged into a bell-jar of carbonic acid, a much graver sound is produced. Glass vessels containing hydrogen and carbonic acid emit very different sounds when struck. A glass jar containing carbonic acid, which is half again as heavy as the air, emits a dull heavy sound. This is strongly indicated when the rim of a glass containing effervescing champagne or soda-water is struck by a hard substance. So long as the escape of carbonic acid continues, the sound is dull, as if the glass were cracked. As it escapes, the glass acquires its usual clear ringing sound.

That water is a good vehicle of sound is proved by the distinctness with which the blows of workers around a diving bell are heard above;—by the fact, well known to sportsmen, that fishes hear very acutely. If a bell were rung under water, and a person were also submersed in water, the sound would be heard by him even better than if both were in the air, but the sound is much graver.*

485. The following are instances of sound conveyed by *solids.* A scratch of a pin at one end of a wooden log is distinctly heard by a person applying his ear at the other end, although through the air it may not be audible, even to the person who makes it. The distinctness of the sound is sometimes taken as a test of the quality or condition of the beam. Savages often discover the proximity of enemies, or of prey, by applying an ear to the ground and hearing the tread. The approach of horsemen at night is easily discovered anywhere in the same way. The report of a cannon placed on ice is carried much farther and faster by the ice than by the air around. In the military operation of mining, or cutting a way under ground for the purpose of entering a citadel or blowing up fortifications, the approach of the enemy has been discovered by the subterranean sound of the pioneers' tools. The awful muttering of earthquakes is merely the sound of subterranean explosions, conveyed from amazing distances by the solid earth.†

Singular noises, heard during the dead of night, and which by the superstitious had been deemed supernatural, have often been eventually discovered to be sounds conveyed by the solid wall of the house from some adjoining building.

It is easy to ascertain whether a kettle boils by putting one end of a stick or poker on the lid and the other end to the ear; the bubbling of the water then appears as loud as the rattling of a carriage in the street, although another person sitting near does not hear it at all. A slight blow given to a steel poker or a steel triangle, of which one end is held to the ear, produces a sound which is even painfully loud.

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* A remarkable exemplification of the power of liquids to transmit mechanical pulses or shocks, analogous to those of air in sound, was given by an explosion of nitro-glycerine off the coast of Oregon in 1874. Vast numbers of fish were caught, either stunned or quite dead for a considerable space round the seat of explosion. Similar effects have also been observed after the firing of "torpedoes" under water.

† The late Sir Charles Wheatstone showed, as far back as 1831, that musical sounds might be readily transmitted through solid linear conductors. An experiment on a large scale was performed at the Polytechnic Institution under an arrangement called the *Telephone.* Performers on various instruments were placed in the basement of the building, and the sounds which they produced were conducted by solid rods through the principal hall, in which they were inaudible, to sounding-boards in a concert room in an upper floor, where the music was heard by the audience precisely as if it were being performed there.

486. The readiness with which solids convey sound is illustrated by the fact that a small musical box, while held in the hand, is scarcely audible, but when pressed against a table or a door, it will rival a little harp. The vibration communicated from the box pervades the whole of the wood, and the extended surface of that acting on the air increases the effect. The construction of violins, harps, guitars, &c., and of sounding-boards generally, is governed by the same law. In the dancing-master's *kit* or small fiddle, which he carries in his pocket, there may be the same strings and the same bow as for a violin, but it has very little sound, because the extent of its surface is so small. A piece of metal called a *sourdine*, when fixed upon the bridge of a violin, damps the sound, because it is a dead mass resisting the motion of the elastic wood. The vibrations of a tuning-fork are heard much more distinctly when the end of the tuning-fork is pressed against the teeth, than when it is simply sounded in air.

A very slight fissure or crack in a solid will break the continuity of the vibrations, and reveal itself by a remarkable change in the sound emitted. A scarcely perceptible fissure in a piece of china or biscuit-ware immediately destroys the usual ringing sound. There is a heavy, dull sound produced when the article is struck, and this is often made a test of the soundness of the article. If the fissure is filled up with cement, cohesion is restored, and with it the original sound. A cracked gold or silver coin is detected by the absence of a ringing metallic sound. The iron tires of the wheels of railway carriages are tested with a hammer. The sound emitted reveals to the experienced ear whether the tire is perfect, or whether there is a flaw in it likely to cause an accident.

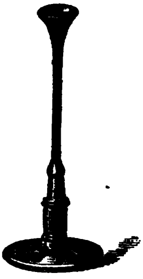

Fig. 130.

487. *The Stethoscope.*—A useful application, in medicine, of this property of solids is the *stethoscope* or *chest inspector*, invented by Dr. Laennec, of Paris. (See fig. 136.) This is a wooden cylinder widening out at one end, which is applied to the chest of the patient while the surgeon places his ear at the other, and detects any derangement of the working of the inward parts, almost as a watchmaker can detect the deranged beating of a watch. Certain diseases of the heart and lungs, and the degree to which they have advanced, may be clearly distinguished by the aid of this instrument.

The actions going on in the chest are, the entrance and exit of the air in respiration, the voice, and the motion of the blood in the heart and blood-vessels;—and so perfectly do all these declare themselves to a person listening through a *stethoscope*, that an ear once familiar with the natural and healthy sounds can instantly detect even slight deviations from them. Hence it is a valuable aid to the physician. The term *auscultation* is applied to the use of this instrument. Independently of its application to the discovery of disease, it enables the physician, by detecting the sounds of the fœtal heart, to determine in any doubtful case the fact of pregnancy. Again, where any doubt is thrown upon the reality of death, there is no more certain method for settling this important question than the application of the stethoscope to the region of the heart. The detection of the movements of this organ, even at unusually long intervals, would indicate life; the absence of them would indicate certain death. The stethoscope, although considered in this place, does not operate only by conducting sound as a solid. It is always tubular, and it receives and conducts the sounds to the ear without spreading, by reason of this tubular form. It acts like an ear trumpet, having a wide base to collect the sound. This should be closely applied to the skin. In a recent improvement of the instrument a vulcanized rubber tube has been substituted for the perforated wooden cylinder.

" *Velocity of Sound.*"

488. The velocity of light, as will be explained in another part of this work, is such, that for any distance on earth its passage may be regarded as instantaneous. The velocity of sound is, however, very much less. If a woodman be observed at his occupation on the hill, his axe is seen to fall a considerable time before the sound of his blow reaches the spectater's ear. The flash of a gun fired at a distance is seen long before the report is heard.

Most accurate experiments have been made to ascertain the velocity with which sound travels in the atmosphere; and it is found to be, in an ordinary state of the atmosphere, about 1110 feet per second; that is, about a mile in four seconds and a half, or about 750 miles an hour, which is ten times the velocity of the wind in a hurricane, and sixteen times as swift as an express train.

By noting, then, how long the flash of a gun is seen before the report reaches the ear, one may learn the distance of the ship or battery from which the gun is fired. The captain of a ship chasing or chased might thus discover its distance by shots fired from the enemy's vessel. In the same manner the distance of a thunder-cloud may be ascertained by the interval between the flash and the peal. When this interval is between four and five seconds, the distance of the cloud will be about a mile; and one reason of the long-continued roll of thunder is, that although the lightning darts almost instantly through a whole chain of clouds, even of miles in length, the sounds proceeding from the different points of its path are only heard in succession, as they arrive at the ear from unequal distances. (The pulse at the wrist of a healthy man is a convenient measure of time for ascertaining distances by the motion of sound, —each beat marking nearly a second, and therefore indicating a distance of nearly a quarter of a mile.)

489. The depth of a deep well, such as that at Carisbrooke, in the Isle of Wight, may be determined in a similar way by dropping a stone into it. The number of seconds which elapse between the time at which the stone is dropped and its meeting the surface of the water, if it can be seen, will allow of a rough calculation. In this case, however, we must estimate and allow for the time which the stone occupies in falling, according to the laws described in a former part of this work.

A long line of muskets fired at the same instant cannot appear as a single report to any person who is not in the centre of a circle, of which the line forms a part; and a company of soldiers, in like manner, cannot simultaneously respond to their officer's command to fire unless they form a circle round him.

An extended orchestra of musicians cannot be heard equally well from all situations near them: hence the absurdity of a monster band where good music is intended.

490. The rate at which sound travels has been determined by a variety of experiments. One of the most simple methods was that adopted by Moll and Van Beck at Utrecht in 1823. This consisted in firing cannon at stated intervals from two places, the exact distance between which was known. The time required for the report to be heard from one point to the other was accurately determined by chronometers

All sounds, whether strong or weak, grave or sharp, travel with equal velocity; in fact, were it not so, there would be no power to appreciate harmony in musical sounds. Some facts, however, appear to show that in certain cases a very intense sound travels with greater rapidity than a low sound.

In damp air sound travels more slowly than in dry air. The elasticity of the air is reduced by moisture, and not only the velocity, but the intensity of sound, is reduced under these circumstances. Thus, it has been observed that the sound of the human voice, the ringing of a bell, the blast of a trumpet, and, indeed, all sounds whatever, are more or less deadened by a damp state of the atmosphere, and are not heard as in dry air.

Dry, frosty air is usually considered, by reason of its greater density, to be most favourable to the transmissibility of sound. Church bells, in country places, are heard more distinctly and with greater intensity in dry than in damp weather, and a change of weather is often predicted by a rustic according to the sound produced upon his ear.

Peschel states that when the air is calm and dry, the report of a musket may be heard at 8000 paces; the marching of a company of soldiers may be heard, on a still night, at a distance of from 580 to 830 paces; a squadron of cavalry, at a foot pace, 750 paces; trotting or galloping, at 1080 paces distant; heavy artillery, travelling at a foot pace, is audible at a distance of 660 paces; if at a trot or gallop, at 1000 paces. A powerful human voice, in the open air, at an ordinary temperature, is audible at a distance of 230 paces. The pace here described as the standard of measurement used for military purposes, represents a yard or rather less. The above figures may therefore be taken as indicating yards.

491. Several circumstances affect the velocity of sound in air; and in making experiments for its determination, due account must be taken of these. First, the *wind* affects it, very much as a current of water affects the motion of a sailing vessel: *i.e.*, it accelerates or retards the velocity, according as it may be moving in the same or in an opposite direction. At equal distances sound is much more intense in calm than in windy weather. Secondly, the *temperature* of the air has a marked influence on its rate of conveying sound. Increase of temperature (see Art. 413) augments the elasticity of air, and therefore, as may easily be conceived, increases the rapidity with which individual particles will deliver the sound-pulsations. The velocity increases about 1·1 foot for every degree of the thermometer above 32°. Thus the velocity of sound in air of the same temperature as freezing water, has been found to be only 1089 feet per second, while at the temperature of 60° F. it is 1120, and at 80° F. it is as high as 1140 feet per second. (See Art. 104.) Thirdly, for the same temperature and elasticity, the velocity of sound varies with the degree of *density* of an aërial or gaseous substance. In hydrogen, which, with the temperature and elasticity of common air, is only one-sixteenth of its density, sound travels four times faster than in air; while in carbonic acid gas, which is heavier than air, sound passes more slowly.

The subjoined figures represent in metres the relative velocity of sound in the different gases at the temperature of 32° F.:—Carbonic acid, 261; oxygen, 317; air, 333; carbonic oxide, 337; hydrogen, 1269. These results are derived from the experiments of Dulong. Sir David Brewster states that in sulphurous acid gas sound moves only at the rate of 751 feet in a second, while in hydrogen it moves at the rate of 3000 feet in the same period of time. (See Art. 539.)

From the known density and elasticity of air, Newton calculated that the velocity of sound in it, at 32° F., should be 916 feet per second; and the difference of nearly one-sixth, by which his theoretical calculation fell short of the ascertained velocity, baffled the ingenuity of the profound philosopher. The true explanation was afterwards given by the French mathematician Laplace. He considered that the sound-pulse, in its passage through the air, produced in its alternate condensations and rarefactions an alternate heating and chilling of the air, effects which combined to increase the difference of elastic force in the two portions of the wave, and so to increase the rapidity of propagation of the pulsation.

492. In liquids and solids, sound travels much faster than in air, not on account of the closer proximity of the particles, but rather by reason of the superior elasticity of liquids and solids. Liquids, as we have seen (Art. 294), are almost incompressible; and the greater the force with which they resist compression, the more rapid will be the rebound after compression, and the more rapid, therefore, will be the passage of sonorous pulses through them.

In water a wave of sound passes four times as rapidly as in air. The velocity has been estimated at about 4708 feet in a second of time. Some experiments made on the Lake of Geneva, in 1827, by Colloden and Sturm, showed that the velocity in water, compared with air, was as 1435 to 333. In saline solutions it is said to travel still more rapidly than in water.

Sounds are not readily transmitted from air to a denser medium like water. Thus, blows struck on a diving bell thirty feet below water may be distinctly heard at the surface of the water, but a sound immediately above the water will not be heard by persons within the bell.

493. In solids sound travels more rapidly than in liquids. Its velocity in solids has been estimated at 11,280 feet in a second (Art. 104), but the velocity is found to vary according to the nature of the solid. Thus, in the metals it is from 4 to 16 times that in air. If the rate of transmission in air is taken as 1, that in gold is 5; in silver and platinum, 8; in copper, 11; in steel wire, 16.

Biot performed a variety of experiments on the velocity of sound in cast-iron, using for this purpose the water pipes of the city of Paris, which were pipes 3000 feet in length. He found it to be 10½ times greater than in air. In ice sound travels at about the same rate as in water; and in glass, Chladni found that its velocity was 17 times greater than in air. (For another mode of measurement see Art. 539.) The same observer found that in *woods* it was from 10 to 17 times quicker than in air. This shows that it is not mere density or closeness of the particles which is the explaining cause. If air = 1, *beech* and *pine* = 10; *ash*, *alder*, *fir*, and *acacia* = 15; and *aspen* = 16. This is the velocity along the fibre, which is in general three or four times greater than that across the fibre; a striking illustration of the difference of physical properties due to mere molecular arrangement.* (See Art. 538.)

The conduction of sound by solids, and especially by wood, is well illustrated in the telegraph posts, between which lines of 180 feet of metallic wire are stretched. Under a gentle wind these long wires vibrate and produce a loud sound, not always heard in the air, but rendered immediately perceptible when the ear is placed against the wooden post. This sound sometimes amounts to a musical murmur rising and falling with the wind, and at others to a roar like the escape of high-pressure steam from a distant locomotive.

It has been shown, however, that the velocity is affected by the strength of the sound; strong sounds travel more quickly than weak ones. The difference of velocity in solids and in air, may be readily heard by applying an ear to a wall or the end of a long iron pipe, while a person strikes the wall or pipe with a hammer

* According to Sir David Brewster sound moves through tin at the rate of 8175 feet, and through iron, glass, and some kinds of wood at the rate of 18,530 feet in a second.

at some distance. Two sounds are heard, the first through the solid, followed by the second through the air, the interval being quite appreciable.

494. Sound, like gravitation, light, heat, or any other uniformly spreading influence, follows the law of *the intensity being inversely as the square of the distance* (see Art. 19).

Thus, at twice the distance, sound has only one fourth of its intensity; so that to make himself heard at this distance, a man must raise his voice not twice only, but to four times the pitch. Hence four bells, or four cannon, would have the same strength in sound as one bell rung or one cannon fired at half the distance. But if, instead of being allowed to spread on all sides, the sound be confined in a long smooth tube, it suffers little diminution of intensity by distance. Thus a watch placed at the end of a long gas-tube, without any sharp bends in it, may be distinctly heard ticking at the other end of the tube, though its beats are altogether inaudible through the air. A continuous plank or metallic rod has the same power of sound-conduction. A conversation has been held in an ordinary tone of voice between two persons through empty water-pipes nearly three-quarters of a mile in length. The use of *speaking tubes* in manufactories, business establishments, hotels, and even private dwelling-houses, is now quite common. These tubes operate by confining the undulations of sound and preventing them from spreading or radiating in all directions. The sides of the tube not only confine the sound, but produce a continued reflection of it.

"*Reflection of Sound. Echoes.*"

495. As a wave of water is turned back by a smooth wall or other such obstacle, so the pulses or waves of sound are regularly reflected from flat surfaces. After reflection, it appears just what it would have been at the same distance beyond (had there been no obstacle), only moving in a different direction. A wave of sound falling perpendicularly on a wall, returns with equal velocity in the same direction until it reaches the spot from which it emanated, and it thus produces what is called an *Echo.** Flat

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* This reflection, owing to the nature of the medium conveying sound, takes place in spherical or concentric undulations, which spread as if they had emanated from another centre placed at an equal distance on the other side of the obstacle which reflects them.

In order that an echo should be heard by the person making the sound, reflecting surfaces on a large scale are often found among rocks and hills; and hence probably arose the beautiful fiction of the ancient poets, that Echo was a nymph who dwelt concealed among the rocks; a fiction which has its counterpart in the wonder and delight with which a child listens to his own shrill call responded to within some wood or from some bold precipice by an unseen imitator. It does not require a hard surface for the reflection of sound. It is easily reflected from the smooth surface of water, whether as a liquid or in vapour. Clouds reflect sound and to this, probably, is partly due the reverberation of thunder. Even when the rays of sound pass into air of a different density they undergo reflection.

496. The quickness with which an echo is returned to the place where the sound originates, depends of course upon the distance of the reflecting surface; and, as sound travels 1120 feet in a second, a rock at half that distance, or 560 feet, returns a sound exactly in *one second.* If five syllables can be pronounced in a second, the whole five may, in such a case, be echoed distinctly, but the end of a longer phrase would mix with the commencement of the echo. If the echoing surface be only $\frac{1}{5}$th of 560 feet, that is 112 feet, distant, then only the last syllable will be echoed; if 224 feet, two syllables, and so on. It of course follows that when the ear is unable to distinguish the original sound from its reflection, there will be no echo. The sound is simply prolonged and rendered louder. It is stated on reliable authority that a good ear is able to perceive clearly nine sounds in a second of time; *i. e.*, the sounds to be heard singly, must succeed each other at intervals of $\frac{1}{9}$th of a second. The least distance at which it is possible for the sound and echo to be perceived distinctly, will be that which the wave of sound can traverse so as to impinge on the reflecting surface and return thence as a reflected wave in $\frac{1}{9}$th of a second of time. As the average velocity at a medium temperature is 1120 feet in a second, then 1120÷9 will give 125 feet for $\frac{1}{9}$th of a second. Hence it follows that half of this distance, 62–64 feet, will be the least distance at which the reflecting surface must be placed in order to produce a perfect echo.

Where there are many reflecting surfaces placed at proper angles

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he should be directly in front of the reflecting surface. If placed obliquely to it, the sound will be reflected in the opposite direction, and may be then heard by another. It follows the same law as a ball thrown obliquely against a wall rebounds from the wall. (Art. 484.)

to each other the sound may be reflected and the echo repeated many times. At the Villa Simonetta, near Milan, the sound of a pistol is repeated from forty to fifty times, and a building at Pavia was so constructed that in answer to a question, the last syllable was repeated thirty times.

497. *Acoustic transparency and opacity of the Atmosphere.*

These terms have been employed by Professor Tyndall to denote remarkable conditions of the air with respect to the transmissibility of sound. This subject has an important bearing upon the employment of sonorous or fog signals at sea, or along a dangerous line of coast. The recent accident off the coast of Ireland, in which, during a fog, the *Iron Duke* ran into and sank the *Vanguard*, has imparted an additional interest to this subject.

Professor Tyndall, in the course of numerous experiments on fog-signals made for the Trinity House in 1873, found that the permeability of the atmosphere to sounds underwent frequent and rapid changes for which it was not always easy to account. The instruments used by him were chiefly trumpets blown by powerfully compressed air, as well as guns. On some days the horns were not heard at a distance of two or three miles, while on other days, under an improved condition of the atmosphere, they were heard at six and eight miles from the coast; and on one day, in June, in which the sky was loaded with dark and threatening clouds, they were well heard beyond *nine* miles. On another occasion the direct or axial blast of the horn was heard at ten and a half miles, and even at the Varne light-ship, which is nearly thirteen miles from the Foreland, where the experiments were made. It was noticed on this occasion that the atmosphere had become decidedly clearer *acoustically*, but not so optically, for a thick haze obscured the white cliffs. On days of far greater optical purity, the sound had failed to reach one-third of the distance, and the conclusion drawn from repeated observations is, that it is a delusion to make optical purity or clearness of the atmosphere, a measure of acoustic transparency or permeability to sound.

This remarkable result, which is opposed to general belief (see Art. 490) is ascribed by this experimentalist to the production of *acoustic clouds* of invisible vapour impervious to sound. The sound-waves, in fact, are thrown back or reflected from these clouds as the waves of light are from an ordinary cloud. The effect of this reflection is to produce audible echoes of great strength and duration, the direction in which the sounds returned, being always that in which the axis of the horn was pointed. This, probably, is the first occasion on which audible echoes have been proved to be reflected from an optically transparent atmosphere. The obstacle which reflects the sound-waves is quite invisible, but appears to be as impermeable to them as if a solid wall had intervened. Thus it was found that at mid-day in July neither guns nor trumpets could pierce the transparent air to a depth of three, and hardly to a depth of two, miles. It has been established by experiment that layers of dried air alternating with layers of air saturated with the transparent vapour of a volatile liquid have the property of powerfully intercepting sound.

It has been hitherto received as an established fact (Art. 490) that fogs arrest sound, and by producing a number of reflections among the aqueous particles which constitute them, either deaden it or rapidly extinguish it. In very dense fogs this may occur, but in a hazy state of the atmosphere sufficient to conceal distant objects from vision, sound, according to Tyndall, is capable of traversing the medium for greater distances than in clear weather. The usual statement that fogs always deaden sound, is thus proved to require some qualification.*

It would also appear from these experiments that heavy rain does not obstruct the passage of sound; and from some observations made in the Alps, Professor Tyndall states that a fall of snow does not interfere with its transmission.

498. *Reversibility of Sound.—Acoustic Reversibility.*—The fact that sound is thus reflected or turned back in a clear or transparent atmosphere, may explain why at a given point the sound produced by cannon may be heard at some places but not at others which are equidistant from the spot. Thus a sound might be heard at a distance of fifteen miles in one direction, but at not more than five miles in another. Again, it has been found as a still more remarkable fact that cannon may be fired in two places at regular intervals, but the number of reports heard at one place will be fewer than those heard at the other. In June, 1822, experiments were made with cannon near Paris by a Commission of scientific men appointed for this purpose, with a view of determining the velocity of sound. The two stations were about twelve miles apart. So different was the transmissive power of the atmosphere, that on one occasion, while every shot fired at M. was heard at V., only one shot out of twelve fired at V., was heard at M. There was no wind to account for this, and the movement of translation, such as it was, was against the direction in which the sound was best heard.

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* Mr. Douglas stated at a meeting of the Institution of Civil Engineers, that he had distinctly heard in a fog at the Smalls Rock in the Bristol Channel, guns fired at Milford Haven, twenty-five miles away, and Mr. Beazely had heard the Lundy Island gun at Hartland Point, a distance of twelve miles, during a dense fog.

In the absence of wind, these facts appear to be difficult of explanation. Professors Stokes and Reynolds assign the loss of sound under these circumstances to *refraction* and not to reflection. They affirm that the rays of sound, like those of light and heat, are subject to refraction when they pass from one medium into another of different density.* The sound, under these circumstances, is lifted from the ground, and may be heard at a high but not at a low level. This may be either the effect of wind or variations in temperature. The wind moves with different velocities on the ground and at an elevation above it, and sounds proceeding against the wind are lifted up off the ground ; hence the range of sound is diminished at a low elevation.

A difference of temperature affects the velocity, and a difference of velocity will cause the sound to be lifted. Balloon-observations have shown that when the sun is shining with a clear sky, the variation of temperature is one degree for every hundred feet, and with a cloudy sky, half a degree. Every degree of temperature adds nearly one foot per second to the velocity of sound (Art. 491). This difference is sufficient to cause the rays of sound to be refracted upwards and lost to a person placed at a low level. But on a cloudy day, in which the difference of temperature and refracting power of the air were less, they might be heard to a greater distance at the lower level.†

499. The breadth of a river might be roughly ascertained if there were an echoing rock on the farther shore. A perpendicular mountain side, or lofty cliffs, such as in many parts skirt the British coasts, return a loud echo of artillery, or of thunder, to a distance of several miles.

If two bold faces of rock or wall be parallel to each other, a sound produced between them is re-echoed several times, playing like a shuttlecock from one to the other, but becoming fainter each time until heard no more. This kind of echo or reverberation may be heard on a grand scale during a thunder-storm in the long valleys of the Alps. In some situations, particularly when the sound travels thus above the smooth surface of water, a pistol-shot may be counted forty times.

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* The refraction of sound has been experimentally proved by M. Sondhauss. Biconvex lenses of large size, constructed of collodion tissue, were filled with carbonic acid gas. Sounds transmitted through these transparent gaseous lenses were refracted to a focus on the other side. They were more distinctly heard at the focal points than at other parts equidistant. (Ganot.)

† Proceedings of the Royal Society, April, 1874.

Sound is always reflected from the walls of every room; but in rooms of ordinary size the time occupied in the impulse and reflection is so short that the interval is inappreciable to the ear. The original and reflected sounds are heard simultaneously; but in an unfurnished room, with bare walls, the effect of this reflection is observed to intensify the sound, and produce what is called resonance, a subject which will be considered hereafter. In rooms of large size the blending of the reflected with the original sound, forms a great drawback to their use for music or public speaking.

The remarkable resonance of narrow inclosed spaces depends on a continued reverberation.* In wider spaces it may modify the effect of music by converting a simple melody, which is a *succession* of notes, into a harmonized piece, where *companion* notes are heard. Resonance injures the distinctness of speech, so as even in some ill-contrived halls of assembly, or theatres, to render the articulation of a speaker unintelligible.

It is worthy of remark that a small apartment or confined space with parallel walls has a certain musical note proper to it, heard after any blow, as of a hammer, the pitch of which (see Art. 496) depends upon the number of pulses or repetitions of a sound produced there in a given time by the returns from its walls. The velocity of sound being uniform, this number must depend on the size of the apartment.

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* In the Speedwell Mine at Castleton, in Derbyshire, the galleries are flooded with water. In one spot there is a cavern in the limestone rock reaching to an enormous depth below and to a great height above. The effect of turning a portion of the water into this cavern is extraordinary. The sound exceeds that of thunder, and causes the slender wooden bridge, upon which the spectator stands, to tremble beneath his feet. Some seconds elapse before the sound of the falling water is heard, and this pause is succeeded by a continued reverberation from the sides of the cavern and the arched vault above.

Certain natural caverns opening to the sea permit the phenomena of reflected and reverberated sound in a most remarkable degree. The cave of Nero in the island of Capri, Fingal's Cave in Staffa, and Dolor Hugo on the coast of Cornwall are examples of this kind. When the sea is calm, and a sound is made in the centre of the cavern, which is generally domed, there is a complete reflection from the surface of the water to the dome, and a powerful reverberation from all parts of the dome to the centre.

500. There is a curious effect of echo which both illustrates the nature of the phenomenon, and proves that *a tone* or musical sound is merely a repetition of pulses following each other very quickly and at regular intervals. A sharp sound, such as the blow of a hammer, occurring near the end of an iron railing, formed of square bars, is echoed to a corresponding place on the other side by every bar in it; and as the echoes do not return all at once, but in regular succession according to the increasing distances of the bars, the consequent regular succession of slight pulses, with uniform and small intervals, affects the ear, not as the echo of a single blow, but as a continued musical tone, the pitch of which depends on the distance of the bars from each other. The writer of this had observed, in passing on horseback along a particular portion of road, where there were first a length of plane wall and then two lengths of wooden paling with rails or bars overlapping at the edges, and the rails of one length being narrower than those of the other—that as he neared the palings there was a clear echo of the horse's cantering feet, and also a ringing sound for every step of the horse. He at first concluded that the road there was singularly hard, although that did not appear, and he slackened the horse's pace, until observing one day that the ringing sound was of a different pitch near the two pieces of paling, and such as to correspond with the different width of the rails, the true explanation occurred to him that the sound was an echo of the nature above described.

501. That an echo may be perfect, the reflecting surface must be smooth, and of a regular form; for a sound-wave rebounds according to the same law as an elastic ball, such as a billiard ball rebounding from any surface on which it impinges. When a billiard ball strikes a side of the billiard-table directly, or perpendicularly, it returns or rebounds exactly along the line of its approach; but when it strikes obliquely, it goes off on the other side, the line of its rebound making the same angle with the side of the table as the line of its approach. This law of impact, which holds equally for liquid waves, for aërial waves, and for rays or waves of light, is expressed shortly in these words: "the angle of reflection is equal to the angle of incidence," —and the velocity of the reflected sound is equal to that of the waves which impinge on the reflecting surface (Art. 495). A little consideration of this law and of the annexed figure (137), will show that a regular concave surface, such as *e g*, may concentrate sound, and bring all the rays which fall upon it, as from *a b c d*, to a common centre or *focus*, *f*, and so produce there a very powerful effect.

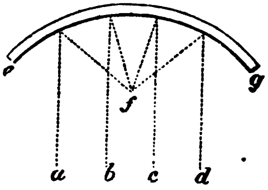

Fig. 137.

If a watch is placed within the focus, *f*, the ticking will be plainly heard in the space within which the rays, *a b c d*, are reflected, but not at a little distance on either side. A similar reflector placed at some distance in front of this, will receive the parallel rays of sound and cause them to converge to a focus. The ticking of the watch may be heard at this focus by the ear, or by means of an ear trumpet, as distinctly as at the focus, *f*.

On the other hand, an irregular surface will reflect impinging air-pulses in different directions, causing a mutual interference in place of mutual concentration. We thus see the reason why an echo is much less perfect from the front of a house which has windows and doors, than from the plane gable, or any plane wall of the same magnitude—and why the resonance of a room is so irregular and indistinct, when the room contains curtains, carpets, and other furniture, presenting numerous irregular surfaces, or when there is a crowded assembly. Halls for music have generally plane walls. Theatres for the drama, again, have boundaries broken in all directions by rows of boxes, and various ornaments, in order that distinct echoes may not mix with a speaker's words.

The concentration of sound by concave or hollow surfaces produces curious effects both in nature and in art.

There are remarkable situations, as at the Falls of Niagara, where the sound from a cascade is concentrated by the surfaces of a neighbouring cave so completely, that a person accidentally bringing his ear into the focus, is suddenly astounded, as if all nature were crashing around him. A chair placed in the cave, so that a person sitting down in it has his ear in the focus, insures the success of the intended surprise.

502. The centre of a circle is the focus in which sound issuing from it is again collected after reflection : hence the powerful echo near the centre of a round apartment. An *oval* has two centres or *foci*—one towards each end, as at *a* and *b* (fig. 138)—and the nature of the curve is such, that sound, or light, or heat, spreading around from either of the foci, as *a*, by obeying the law of reflection above stated, is all directed from the various points, as at *c*, *d*, *e*, &c., to the other focus, *b*. Hence a person whispering at one focus of an oval room may be heard quite distinctly at the other focus, although he may not be heard by persons placed anywhere else. Such a room might be called a whispering gallery, as whispers would be thus conveyed and heard. Concave surfaces facing each other, as two alcoves in a garden, or covered recesses on opposite sides of a street or bridge, will enable persons seated in their foci, to converse by whispers across louder noises in the space between, and without being themselves overheard in that space.

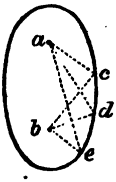

Fig. 138.

As an illustration of this, it may be stated that the stone recesses of old Westminster Bridge were semidomes exactly opposite to each other, and so accurately constructed that a person whispering in the focus, A, of one of these recesses (see fig. 139), could be distinctly heard by another placed in the focus, B, of the opposite recess. The lines drawn from A represent the directions in which the sonorous vibrations were reflected so as to be concentrated at B.

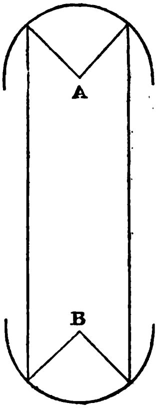

Fig. 139.

Sound is reflected from the *earth*. Persons who have ascended in balloons have been surprised at the distinctness with which voices and the sounds made by animals have been heard at a considerable elevation.

The plane surface of a smooth wall prevents the lateral spreading and dissipation of sound, although only on one side. Thus persons far apart may converse along a smooth wall. For a similar reason the smooth surface of water powerfully reflects sound. The barking of dogs, or the clear voice of a street-crier, in a town situated on the border of a lake, may be heard across the water on a calm evening at a distance of several miles, as the writer one evening perceived near Southampton. The sound of bells, of course, is audible much farther, and in the stillness of night, even the splashing oars of a boat will announce by a reflection of the sound its approach to persons waiting at a great distance.

503. If a wall be curved inwards, or concave, it not only prevents the spreading outwards of any sound which passes along it, but is constantly condensing the sound waves by driving them from the external part inwards. Hence, in a circular space, such as a gallery under a dome, as in St. Paul's Cathedral, persons close to the wall may whisper to each other and be heard at great distances, the sound being concentrated at a point exactly opposite to that at which it issues from the mouth of the speaker. Thus, in fig. 140, the interior of the dome or *whispering gallery* is represented by the circle, but it is, in fact, a hollow hemisphere, adapted to reflect sound in all directions, and concentrate them on a single point. Thus a sound emitted at A reaches the concave surface at B, and is reflected to C. In the same manner the sonorous vibrations which go from A to D and F, are reflected respectively to E and G, and from these points by a second reflection to C. All intermediate rays which reach the interior of the dome are carried by reflection to C, and thus it happens that if a door at A be shut with violence, the sound at C resembles thunder in its impression on the ear.

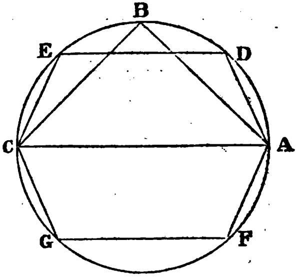

Fig. 140.

504. The *Ear-trumpet* (fig. 141) is a tube wide at one end, A, where the sound enters, and narrow at the other, B, where the ear is applied: its sides are so curved that, according to the laws of reflection, any sound which enters is condensed towards the narrow end. Considering the sonorous vibrations to enter by the lines C, D, E, they are reflected from the points F, G, H, and are concentrated in the smaller end of the tube, B. By using such an instrument, persons who have had their sense of hearing impaired, may obtain from it such aid to the ear, as spectacles give to the eye.

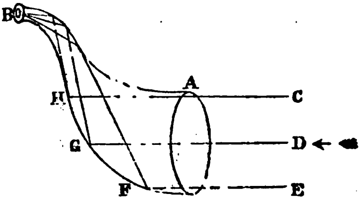

Fig. 141.

The concave hand held behind the ear helps to concentrate the sound, as is illustrated by almost any ordinary assembly of listeners, particularly if the speaker has a weak voice or is distant. A good substitute for the hand is a small cup of wood or other light material: and two such cups—or *ear-shells*, as they may be called—joined by an elastic wire, might be very advantageously worn by deaf persons. The writer of this once tested the value of the contrivance by experiment, and the result was very satisfactory.

The various forms of ear-trumpet act more powerfully than this combination, particularly the long flexible tube with a small trumpet-opening to be held near the mouth of the speaker, while the hearer places the other end to his ear; but all these occupy inconveniently the hands of one or of both parties, while the ear-shells no more incommode a person using them than a pair of spectacles.

505. A notorious instance of a sound-collecting surface was the *Ear of Dionysius*, in the dungeons of Syracuse; the roof and walls of the prison are said to have been so formed as to collect the words and even whispers of the unhappy prisoners, and to direct them along a hidden conduit to where the tyrant sat listening. The wide-spread sail of a ship, rendered concave by the breeze, is also a good collector of sound. It happened on board a ship sailing south in the Atlantic, towards Rio de Janeiro, while out of sight of land, that one day, persons on the deck, when near a particular part of it, thought they heard distinctly the sound of bells. All were attracted to listen, and the phenomenon was mysterious. Weeks afterwards it was ascertained that, at the time of observation, the bells of the city of St. Salvador, on the Brazilian coast, had been ringing on the occasion of a festival; their sound, therefore, favoured by the wind at the time, had travelled over at least 100 miles of smooth water, and had been condensed by the concave sail to a focus on the deck of the vessel where it was listened to. It appears from this that a great concave might be constructed having a like relation to sound that a telescope has to light. A gentleman while sitting, on the 18th of June, 1815, by the wall of his garden, on the heights near Dover, believed that he heard distinctly the firing of the cannon at the great battle of Waterloo then raging in Belgium. The perception of sound may in this case have been partly aided by reflection. In remote country places there is reason to believe that the reflection of distant sounds from the walls of lonely and uninhabited houses has sometimes led to the report that they were haunted.

506. Apart from any reflection of the sound-waves, sounds may be heard at considerable distances when the temperature and other atmospheric conditions are favourable. Peschel states that the greatest known distance to which sound has been carried through the atmosphere is 345 miles, as it is asserted that the very violent explosions of the volcano of St. Vincent have been heard at Demerara. There is no doubt that sound travels to a greater distance and more loudly on the earth's surface than through the air. Thus in the wilds of Africa, the roar of the lion is heard for many miles around. This is owing to the animal placing its nostrils within a short distance of the ground, and the transmission of the sound by the surface. It is stated on good authority that the cannonading at the battle of Jena, in 1806, was heard, though but feebly, in the open fields near Dresden, a distance of ninety-two miles; while in the casemates of the fortifications (underground) it was heard with great distinctness. So it is said that the cannonading of the citadel of Antwerp, in 1832, was heard in the mines of Saxony at a distance of 370 miles.

507. The *Speaking-trumpet* is precisely the reverse of the ear-trumpet, but it is constructed according to the same law of reflected sound, with the view of directing the strength of the voice to a particular point. It is usually of a funnel shape (fig. 142), but its proper form is that of a parabolic curve. The rays of sound are reflected from the interior as the words are spoken at the smaller end of the tube, and are carried in parallel lines, represented by the letters A B C D E, to a considerable distance. They prevent the sound from spreading as it issues from the mouth, and set the air in vibration more forcibly in the direction in which the axis of the trumpet is held, than if they had issued directly from the mouth of the speaker. This will be understood by reference to the figure. The dotted lines show the course which the rays, A E, would take if the trumpet were not used. A strong man's voice sent through a trumpet from eighteen to twenty-four feet in length has been heard at a distance of three miles. (Peschel.) The longer the trumpet the greater the distance to which the sound is carried. The sea-captain uses it to hail ships at a distance, or to send his orders aloft, where the unaided voice would be lost in the noise of the wind and waves. A similar form of mouth is used for the military trumpet, and it renders sounds audible even amid the uproar of battle.

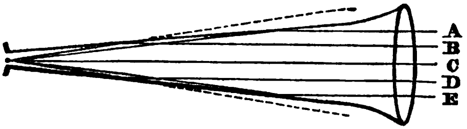

Fig. 142.

508. Some amusing effects have been produced by operating on sounds with tubes and concave surfaces. What was termed the *Invisible girl* was an arrangement whereby the questions of visitors were received through a kind of ear-trumpet connected with a suspended hollow sphere. The sounds were transmitted by tubes concealed in the framework of the apparatus, and thus conveyed to the ear of a woman who was placed in an adjoining apartment; she returned an answer through the speaking-tube to any question thus put to her. The sound was reflected from the interior of the suspended sphere, and its direction was thereby so changed that it appeared to the listener to issue from its interior. The days of spiritualism had not then commenced, or this ingenious adaptation of scientific principles to a clever deception, might have been fairly classed with some of the optical and other illusions which now impose upon a credulous section of the public.

MUSICAL SOUNDS.

509. Aërial impulses, however produced, if they fall on the ear with sufficient rapidity, give rise to the sensation of continuous sound. This sensation is pleasing, and the sound is termed *musical* when the impulses recur regularly or at equal intervals of time; if they recur irregularly, the effect is displeasing, and the sound is called harsh or discordant.

If a toothed wheel be made to turn, and the edge of a piece of quill or of cardboard, be placed against the teeth, every tooth can be distinguished, and every blow will be separately heard so long as the wheel turns slowly; but as the rate is increased, the teeth disappear to the eye; and the ear, failing to detect each separate blow, combines the series into *one* continued sound or *tone*, the character of which changes with the velocity of the turning wheel.

In like manner the vibrations of a long harp-string, while it is slack, are separately visible, and the air-pulses produced by it are separately audible; but as it is gradually tightened, its vibrations quicken, so that at last, where it is moving, the eye sees only a shadowy line broader near the middle: and the distinct sounds which the ear lately perceived seem to run together, and are felt as one uniform continued tone, which constitutes the note or sound then belonging to the string.

510. It is the elasticity of any string used to produce a tone which causes the repetition of the percussions, and therefore the continuance of the sound. Its vibrations are precisely analogous to those of the pendulum already considered (Arts. 286 and 287), the force of cohesion taking the place of the force of gravity. A large vibration of a string, like a large oscillation of a pendulum, occupies very nearly the same time as a smaller, because the farther the string is displaced, so much more forcibly, and therefore more quickly, is it pulled back again by its elasticity. Hence the uniformity of the sound produced by a musical string, is not affected by the different force with which the finger of the player may touch the string.

Where a continued sound is produced by impulses which do not, like those of an elastic body, follow in regular succession, the effect ceases to be a clear uniform sound or tone, and is called a *noise*. Such is the sound of a saw or grindstone—the roar of waves breaking on a rocky shore, or of a violent wind in a forest—the roar and crackling of houses or of a wood in flames—the mixed voices of a talking multitude—the diversified sounds of a great city, including the rattling of wheels, the clanking of hammers, the voices of street-criers, the noises of manufactories, &c. These rough elements, however, mingle so completely in the distance, that the combined result has been called "the hum of men," from analogy to the smooth mingling miniature sounds which constitute the hum of a bee-hive.

For the production of a tone, it is of no consequence in what way the pulses of the air are caused, provided they follow with sufficient rapidity and regularity. The musical sound produced by the motion of a gnat's wing was long supposed to be the voice of the insect; but because it ceases instantly when the fly comes to rest, it is now believed to depend altogether on the motion of the wings. Similar effects are produced by passing a finger-nail quickly across the teeth of a comb or the ribbed surface of a piece of hair-cloth, or along the surface of a large harp-string covered with wire. The flapping of a pigeon's wings, the clacking of a corn-mill, and the noise of a stick pulled along a grating, are not tones, only because the pulses follow too slowly.

511. The most simple and familiar instance of sounding vibrations is that of an elastic cord or wire extended between two fixed points, as in stringed instruments of music, such as the violin, pianoforte, guitar, harp. The vibrations of a solid rod of metal, glass, or any other elastic substance, fixed firmly at one end and left free at the other, are a source of musical sounds, as in a tuning-fork, or the reed-pipe. A schoolboy thus sticks the point of his penknife into the bench, and by one touch makes it produce a continued uniform sound of considerable duration.

In "musical boxes" the notes are produced by the vibration of little rods of steel varying in size, fixed by one end, like the teeth of a comb, and touched by small pins or points projecting from a turning barrel. Any elastic flap, as of metal or of tough wood, fixed over an opening, so as to stand away from it a little when not pressed by passing air, but to close the opening momentarily if so pressed, becomes a sounding reed when air is gently forced through the opening. Thus, the air first pressing on the flap to close it, causes a momentary interruption of the current, but the flap immediately recoiling from the blow by its elasticity, again opens the passage, and the continued rapid alternation of the shutting and opening induces pulsations of the air sufficient to produce a musical note. The reed of a clarionet is a thin plate of elastic wood, made to vibrate in this way. The drone of the bagpipe and the common straw-pipe are reeds of nearly the same kind. The Chinese mouth-organ, and the class of instruments represented by the symphonion and concertina, have reeds which differ from these only by beating *through* the opening instead of merely *on* its face.

Elastic rods simply resting on supports at both ends, or suspended by their middle, will also vibrate: a musical instrument is thus made of pieces of glass laid upon two strings, and struck by a cork hammer: in the island of Java, a rude instrument of the same kind is made of blocks of hard elastic wood.

512. The mere rotation of a toothed wheel in air will produce a musical note, if the teeth be large enough to impel a sufficient quantity of air. Akin to this mode of producing sound is the youthful amusement of whirling by a string round the head a piece of lath or of tin plate notched on the edge. So long as the motion is moderate, the sound is dull and heavy, forming to the mind a sort of miniature thunder: as the speed is increased, the note rises to a shrill scream.

A very simple and most instructive mode of producing a note is by a succession of puffs of air. For this purpose we may take a disc of cardboard, having a series of holes punched at equal distances in a circle round the centre of the disc. If, now, by means of a gyroscope or a heavy top, this disc be rapidly whirled, while through a tube or pipe we blow steadily against the circle of holes, it is obvious that the blast of wind will pass through the disc by a succession of puffs, or as each hole comes round opposite the mouth of the pipe. If the rotation of the disc be sufficiently rapid, these puffs combine to produce one continuous sound or note, which rises in height, pitch, or shrillness as the rotation increases ; with a suitable rate of rotation any height of note may be obtained. Thus, with the means of indicating the number of turns made by the disc per second, we know the number of air impulses, puffs, or vibrations corresponding to any given height of note.

This is the embryo of the instrument called the *syren* (to be described farther on), which plays a most important part in the modern physics of music.

513. Those sounds which are termed *musical*, alone merit attention, not only from the pleasure which they are capable of affording to the mind, but from the fact that they alone are regular, and are therefore subject to certain laws which admit of being closely studied.

Musical sounds differ among themselves in three particulars, namely, (i.) intensity or loudness, (ii.) pitch or height, and (iii.) quality, colour, character, or *timbre*, as the French express it.

(i.) The *loudness* or *intensity* of a tone or note depends, in the first place, on the extent of vibrations which the exciting body makes itself, and communicates to the air. If we fix a piece of steel spring in a vice or to a table, the sound which it sets up when it vibrates, is louder the greater the extent of the excursions which it makes. Similarly, the pitch of a tuning fork remains the same, but the loudness of its note is increased by giving it a harder blow. This makes the legs vibrate to a greater extent, and in consequence the air particles also sway to and fro individually through greater distances. For sounds of the same height, the intensity depends on the *energy* of the air-vibrations : and a little consideration of the laws of vibrations generally, shows that for a double, triple, &c., extent of vibration, the intensity is increased four, nine, &c., times.

Intensity depends, secondly, on the mass of vibrating air.

Two tuning forks of the same pitch sounding together give a louder note than either singly; because thereby a greater mass or volume of air is set in pulsation, and the total energy of vibration is correspondingly increased. With the same number of holes in the cardboard disc referred to above, we may vary the intensity of the note by varying the *size* of the punched holes, and so varying the volume of air thrown into pulsations. The loudness of a drum, of a cannonade, or of thunder, is due to the immense mass of air set in motion. For a like reason the sounding-board of a piano, the body of a violin, &c., increase the intensity of the sound by taking up the same vibration as the strings, and by their large surface bringing a greatly increased mass of air into play. The power and quality of stringed instruments generally depend altogether on the facility with which this auxiliary vibrating mass assumes the same rate of pulsation as the string. This reinforcement of sound will be again considered under the head of *Resonance.*

Lastly, the intensity of any note, as of any sound, depends on the *distance* of the sounding body : and diminishes at the square of the rate that the distance increases.

This (see Art. 494) is an immediate consequence of the fact that sound in the open air, spreads uniformly in all directions round about its origin.

> **514.** (ii.) The *pitch* or height of a musical tone—sensibility to which constitutes a musical ear—depends on the rate of the aërial vibration set up by the sounding body ; or, which is merely another way of expressing the same fact, on the number of air-pulsations produced by the sounding body in any space of time, such as a second.

A *low*, *grave*, or *bass*, tone is one of comparatively slow and few vibrations ; while a *high*, *shrill*, or *sharp* tone has quicker and more numerous vibrations.

This general connection between the height or pitch of a musical tone and the number of vibrations may be readily illustrated in various ways :—

It may be roughly shown by drawing the finger-nail slowly and then rapidly across the teeth of a comb. See also for another kind of illustration, Art. 509.

Or, again, by having in the disc referred to in Art. 512, a series of circles, A, B, C, D (fig. 144), round the common centre, each containing different numbers of punched holes, we may show by blowing into the smaller ring, A, first, and then into the others, B, C, D, in succession while the disc is being rapidly whirled, that the height of the note rises with the number of air-pulses produced during one turn of the disc.

515. By an ingenious instrument called the *Syren*, shown in fig. 143, which was contrived by the French philosopher Cagniard de la Tour, the passage of the wind through the holes of the disc is made to cause at once the necessary rotation and pulsation. The wind or air enters by the pipe, A, from a bellows or other source, into the close box, B, in the lid of which is a series of holes corresponding with those in the rotating disc, D, seen above. The holes are not bored directly through, but obliquely slanting in one direction through the lid of the box, B, and slanting in the opposite direction through the disc, D. Thus, according to the principle of "oblique action," already explained (Arts. 375, &c.) the disc is impelled round its axis by the wind as it issues through the lower set of holes into the upper. But, again, the wind cannot pass except when the one set of holes is opposite the other; thus it will escape by a succession of puffs, and during one turn of the disc there will be as many puffs as there are holes in the circle, and they will thus increase in number as the rotation of the disc accelerates. An endless screw on the axle of the syren disc gears into the teeth of a counting-wheel, C, which, with another wheel, E, serves to indicate the rate at which the syren is turning, and consequently the number of pulses made per second.

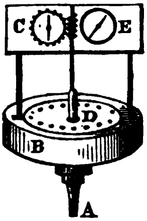

Fig. 143.

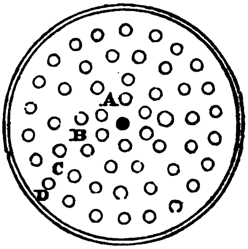

Fig. 144.

With this instrument we can both build up a musical tone out of a number of individual pulsations of air, and we can analyze the number of pulses corresponding to any given musical tone, by bringing the pitch of the syren to coincide with it, and then estimating by means of the counter, C, the pulse-rate.

So long as the rate of rotation, as shown by the indicating hands, remains the same, and therefore the number of air-pulses remains the same, the ear recognizes the same pitch or height of musical tone; but with a variation of the velocity, the ear at once recognizes a difference in the pitch of the tone.

The syren thus demonstrates the cause of, and defines the exact relation between, those differences of pitch which are the basis of the musical sense, and which are discernible, with more or less nicety, by most individuals.

516. Any succession of tones of different pitch is more or less pleasing; but there is a natural selection of tones employed for the creation of musical pleasure, which rise step by step one above another, forming what is called the *musical scale.* These have been very much the same in all ages and among all nations, and they depend on the physiological structure and capabilities of the human ear.

" *The Musical scale.*"

517. The natural steps by which the voice rises, and with which the ear is pleased, form the musical scale; it consists, as is well known, really of eight steps or intervals, by which, starting from any arbitrary note, the voice rises or falls to the satisfaction of the ear.

The eighth note, or *octave,** to the first, has this peculiarity, that it blends indistinguishably with the first; and if we rise, in the same way, to the octave to this second note, and then to the octave to this third note, and so on, the whole set of octaves when sounded together blend most pleasantly. Thus the whole series of musical tones is naturally divided into groups of eight notes each, or octaves, the notes of each group all bearing the same relation to each other.

The notes are commonly named by the seven letters C, D, E, F, G, A, B, the eighth note, or octave, being named C, or C′, and the subsequent notes D′, E′, F′, G′, A′, B′, C″, D″, E″, &c.

The musical steps or *intervals* are named as follows :—

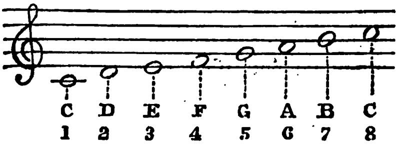

Fig. 145.

C to D a *second.*
C to E a *third.*
C to F a *fourth.*

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* From the Latin, *octavus, the eighth.*

C to G a *fifth.*
C to A a *sixth.*
C to B a *seventh.*
C to C an *octave*, or *eighth.*

The interval between each successive pair of tones is not precisely the same; and it has been long an interesting speculation to what cause the apparently arbitrary selection of notes could be assigned. As long ago as in the age of the Grecian philosopher Pythagoras (B.C. 530), some approximations to the truth had been attained. But with the aid of the modern physical instrument described above as the syren, or even with the simple perforated disc (Art. 512), the following remarkable relations underlying the musical sequence of notes, may be readily demonstrated:—

Relations between the Notes of the Scale.

518. (i.) Suppose the number of holes in the third circle, C (fig. 144), to be sixteen, or double of that in the first circle, A (eight), it is found by blowing first into the one set of holes and then into the other, that the second note is the octave above the first. Hence

One note is the octave of another when its pulse-rate is double that of the former.

(ii.) Suppose that, while the first circle, A, contains eight holes, the second, B, contains twelve, or that B has three holes for every two that A has; then we find, on sounding first A and then B, that the latter is a *fifth* above the former. Hence

One note is the fifth above another when it pulses three times, while the former pulses twice.

(iii.) Suppose that we sound first the set of holes in B, and then those in C, the latter is recognized as the *fourth* above the former. Hence, since the numbers of their holes are as 4 : 3,

One note is the fourth above another when it makes four pulses while the latter makes three.

By a number of such experiments it may be demonstrated that there is always some *simple relation* between the number of vibrations or pulses corresponding to the different notes of the scale. This pulse-ratio may be expressed by a fraction, such as $\frac{4}{3}$, which means that the number of aërial vibrations per second corresponding to the first note bears to the number corresponding to the second note the ratio or relation of 4 to 3.

The following are the *pulse-ratios for the major scale*:—

C to C = 1 : 1 or $\frac{1}{1}$ (first or unison).
D to C = 9 : 8 or $\frac{9}{8}$ (*second*).
E to C = 5 : 4 or $\frac{5}{4}$ (*third*).
F to C = 4 : 3 or $\frac{4}{3}$ (*fourth*).
G to C = 3 : 2 or $\frac{3}{2}$ (*fifth*).
A to C = 5 : 3 or $\frac{5}{3}$ (*sixth*).
B to C = 15 : 8 or $\frac{15}{8}$ (*seventh*).
C to C = 2 : 1 or $\frac{2}{1}$ (*eighth*, or *octave*).

In what is called the ***minor scale***, the interval of a ***third*** has the pulse-ratio $\frac{6}{5}$ instead of $\frac{5}{4}$; the minor interval of a sixth has the ratio $\frac{8}{5}$ instead of $\frac{5}{3}$; and the ***minor seventh*** $\frac{16}{9}$ instead of $\frac{15}{8}$.

519. Reducing by ordinary arithmetic the major scale fractions to one common denominator (24) we obtain the following set of fractions: $\frac{24}{24}$, $\frac{27}{24}$, $\frac{30}{24}$, $\frac{32}{24}$, $\frac{36}{24}$, $\frac{40}{24}$, $\frac{45}{24}$, $\frac{48}{24}$. Hence we see that, if we had a syren disc with eight circles of holes, containing the numbers 24, 27, 30, 32, 36, 40, 45, 48, respectively, we should be able to play the eight notes of the major scale on the instrument. The exact number of air-pulses corresponding to any one note, say the first, which we call C, would depend of course on the rate at which the disc is whirling. But whatever this rate, the others would all follow in regular musical sequence. Thus, given the "vibration-number," or pulse-rate, corresponding to the fundamental, key, or starting note, we can at once determine the pulse-rate or vibration-numbers corresponding to the whole octave.

If the middle C of the pianoforte make, as it is now generally tuned, 264 vibrations per second, then the vibrations of the whole octave are:—

C	D	E	F	G	A	B	C′
264	297	330	352	396	440	495	528.

In the same way we might find the vibration-numbers for all the notes of a piano. From the first A of the bass—of a common seven-octave piano—to the last A of the treble we have a range of from 27 vibrations or pulses per second to as many as 3520. These are not by any means the limits of the musical scale, or of the perception of a musical tone, for the pulses of the Syren begin to assume the character of a tone when they reach 16 per second, and 20 pulses per second may be regarded as giving a sufficiently decided tone. On the other hand, the shrillest note in the orchestra is estimated to have 4750 vibrations per second, and the limits of audibility are not exceeded when 38,000 vibrations are reached. The musical sequence of notes can, however, be fairly discerned only between the limits of 40 to 4000 vibrations per second, just as to the eye, the relative parts of a landscape escape observation beyond a limited distance.

520. *Length of Musical Waves.*—All musical sounds travel through the air at almost the same velocity, namely, 1120 feet per second; and as the time occupied by a wave to advance through its own length is the same as the time of a single vibration of the sounding body (Art. 475), it follows that the length of the aërial waves diminishes as the height of the note increases. For shrill notes they are short and rapid, and for low notes they are long and slow. When the middle C of the piano is struck, it vibrates about 264 times in a second, and hence sets up air-pulses of 1120 feet divided by 264 or 4¼ feet in length. The first A of the bass (in a seven-octave piano) produces air-waves about 41 feet in length, while the last A of the treble sends on pulses not quite 4 inches long (Art. 519). The latter pulses are 128 times more rapid than the former, which are correspondingly longer. If the sensibility of the ear-nerves is to be judged by the range of audibility of musical tones, it far surpasses that of the optic nerves. The former ranges over *eleven octaves*, while that of the latter barely exceeds a single octave.

521. (iii.) The third kind of difference among musical tones is that known as *quality*, *colour*, *character*, or *timbre*.

Loudness, as we have seen, depends on the extent of the air-vibrations, and intensity on their rapidity. But every one knows that sounds of the same degree of loudness and of pitch may be sounded on a pianoforte, a violin, a trumpet, a harmonium, a clarionet, or with the voice, and yet that there is a something which distinguishes the tone in each case, and which enables us to say by which of the instruments it was produced. It is this peculiarity or *quality* of tone which enables us to distinguish the voices of different singers; and even in human speech, qualitative varieties of tone are employed in the formation of the different vowel sounds, which bear to consonants the relation of musical tones to noises.

522. We will now consider to what physical cause, this third peculiarity of tones can be traced. All musical sounds are due to vibratory or periodical motions of the sounding body and the air or conveying medium. Now a vibratory motion may vary (1) in extent or amplitude, (2) in rapidity, or (3) in *mode* or *form*. The two former correspond, as we have explained, to loudness and pitch of tone; the latter corresponds to *quality*.

The adjoining figure (fig. 146) may help the mind to conceive how this may be. A, B, and C are three waves having the same height or amplitude of motion and the same wave-length, and therefore rate of vibration; but obviously the modes of vibration are very different. In A it is smooth and even in its rise and fall, in B it is associated with secondary motions, and in C the motion is slow in its rise and abrupt in its fall. There is little difficulty in conceiving, then, how the number of such variations is almost unlimited; and there is no doubt that to analogous variations in sonorous pulsations the difference of *quality* or *timbre* in musical sounds has to be ascribed.

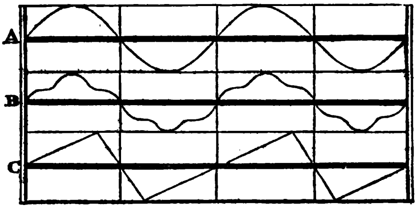

Fig. 146

523. The existence of such varieties of wave-shape or pulse-form does not rest on mere theory, but can be actually exhibited to the eye, and even recorded on paper, by various mechanical arrangements. Perhaps the simplest means of doing this is with the tuning-fork.

For this purpose we fix a small steel or brass tracer to one of the prongs of a tuning-fork by means of a little wax. On striking the fork, or exciting it with a violin-bow, the motion of the tracer will be quite visible, and it may be permanently recorded and its regular or pendulum-like nature shown, either by drawing underneath it a strip of smoked glass or cardboard, as represented in A (fig. 147), or by holding it so that its tracer just grazes a similarly blackened cylinder or glass bottle, B, mounted so that it can be turned regularly. A sheet of paper may be wrapped tightly round the cylinder, and removed with the wavy

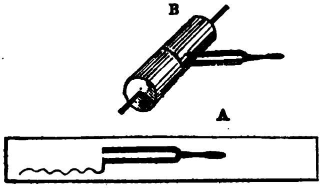

Fig. 147.

trace. In this way a beautiful wavy line of the form of A (fig. 147), is obtained, each wave corresponding to a vibration of the legs of the fork ; and if the cylinder be turning at the rate of once a second, the number of waves that can be counted round it, will correspond to the vibration-number of the note. This is easily proved by making the syren coincide in pitch with the tuning-fork, and then noting the pulse-number indicated by its counter.

As the intensity of the sound falls, the extent of the vibrations diminishes, but the number traced per second remains the same.

524. The *Phonautograph* of M. Leon-Scott is a more elaborate and expensive means of tracing mechanically the sonorous vibrations of any note or sound, or mixture of notes. It is a sort of big artificial ear which reveals these vibrations to the eye. In shape it is like a drum, with a narrow and a wide end, and open at the wide end. Over the narrow end is stretched tightly a delicate membrane, and a tracer of hog's bristle is fixed on this with some sealing wax. Any note played into the open mouth of this instrument causes tremblings of the style or bristle; which, recorded on a rotating cylinder, reveal the nature of the sound.

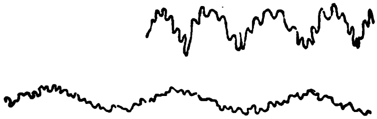

Fig. 148.

The adjoining cuts represent tracings obtained with the phonautograph of sounds whose pitch and intensity are determined by the larger and more prominent waves ; but their *timbre* or quality will be very different from that of other notes whose representative wave-surface is free from the minute serrations visible here.

Harmonics.

525. On attentively examining the sounds corresponding to such complex figures, a moderately delicate ear will detect not one musical tone alone, but a whole series of accompanying higher tones, rising in pitch according to definite laws, but growing gradually fainter as they rise.

To these the name of *harmonics* or *overtones* is applied, the lower tone being the *fundamental*, *prime*, or *governing* tone, which regulates the pitch of the whole compound musical tone. The laws according to which these *harmonics* arise are exceedingly simple, and are as follows :—

First. The ear detects the octave of the fundamental tone; that is, a tone with *double* the number of vibrations which the prime has.

Second. The *fifth* to this latter octave is also heard; that is, a tone making $\frac{3}{2}$ of its vibrations per second, or *three* times the number of vibrations of the *prime* tone.

Third. The second higher octave to the prime is heard; that is, a tone with *four* times the number of its vibrations.

Fourth. The major third to the last, that is, a tone making $\frac{5}{4}$ of its number of vibrations, or *five* times the number of vibrations of the prime.

And so on to tones, growing continually fainter, of 7, 8, 9, &c., times as many vibrations as the fundamental tone.

The series of harmonics arising from any fundamental tone, C, is, in musical language, as follows :—

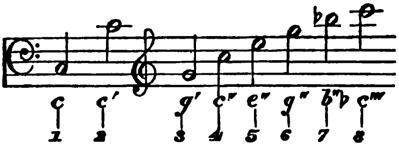

Fig. 149.

This gives the musical notation for the seven upper harmonics to the fundamental tone, *c*, with their vibrational relations to that tone.

526. It is a most remarkable fact, established by the researches of Prof. Helmholtz, that to the variations in loudness and pitch of these upper harmonic tones, the *quality* of a musical note is to be attributed. One musical tone differs from another just as one musical chord differs from another: and the analysis by the ear of such composite tones, is a most wonderful feat, when we consider that the ear is not, like the eye, capable of any comprehensive sweep. It cannot directly reveal the wave-nature of sound, much less discriminate subordinate modifications of the aërial wave-form.

Still the ear can do much more than the eye can do in decomposing compound wave-forms. Any number and variety of sounds may be conveyed at the same instant by the same body of air without destroying their individual effect. Thus, for instance, all the voices of a choir are transported through the same aërial mass, and the ear can single out any one voice, or even analyze the chorus into its constituent voices; in other words, the ear can resolve the complex resultant aërial vibration into its individual components. Similarly, any number of liquid waves may be simultaneously passing over the surface of a lake or of the sea, and the resulting disturbance is a compound of the individual effects. For example, two waves of the form of A and B (fig. 150) would combine into the form C; but the eye on seeing the latter form would be totally unable to analyze it into its two constituent waves, A and B. This, however, which to the eye is nearly an impossibility, is to the ear quite an easy matter.

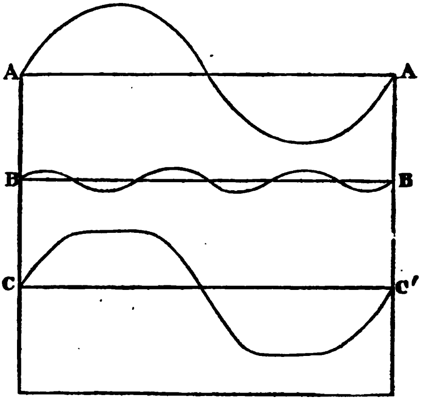

Fig. 150.

Method of observing the harmonics of any tone.

527. The ear, even though unpractised in musical discriminations, may readily observe these *overtones* by a simple contrivance of Prof. Helmholtz, which is an application of the property of

Resonance.

Resonance may be described as a sympathetic vibration, arising from the cumulation of small periodic impulses, imparted by an oscillating body, to another whose period of vibration is synchronous with the first. Thus, the string of a piano, if its damper be gently raised by touching, not striking, its key, will be heard to vibrate in response to the same note forcibly sung or played near it. The sounding-board, taking up the vibrations of the air, communicates them to the string by a succession of small impulses, until they become sufficiently large to be audible or even visible. It is only in the string that vibrates at the same rate as the sounding-board, that the effect of these impulses is cumulative; in the other strings, there is interference and confusion between the pulses of the board and those of the string.

Any elastic body capable of vibrating readily may thus be thrown into resonant or sympathetic vibration. Bell-shaped glasses can be thrown into violent motion, it is said even shivered, by a very powerful and fine voice singing their proper tone into them or near them.

So a tuning-fork at one end of a room will respond to another of the same pitch, struck or sounded by a violin-bow at the other end of the room. But the least difference of pitch destroys the resonance, as may be proved by fixing a little wax to one of the legs of the resounding fork. In like manner a stretched india-rubber membrane may be found to answer the note which accords with its natural period of vibration.

A column of air is an exceedingly sensitive resonator. If a tuning-fork be struck and held over a tall jar, it will be found on slowly pouring in water into the jar that for a certain depth of the water-surface, the tone of the fork is resounded, greatly strengthened, by the jar (see fig. 151). A different pitch of tuning-fork would have a different length of resonant air-column corresponding to it; so that each note has its own resonant air-column which will respond to it when sounded.

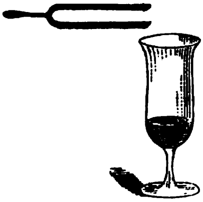
Fig. 151.

528. It is an application of this principle that Professor Helmholtz has made use of for the analysis of harmonics. His resonant air masses, or *resonators*, are formed by glass or brass vessels of the shapes A, or B, in fig. 152. They are open at both ends, the smaller end being inserted in the ear. A series of such resonators is constructed so as to resound each to a note of different pitch. It is evident then that, since the inclosed air-column will respond only to a definite note, the corresponding note may be singled out from any mixture of notes and isolated, as effectively as the chemist singles out by precipitation any ingredient

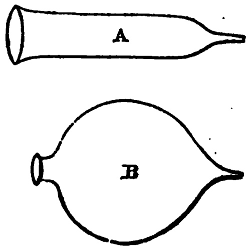

Fig. 152.

he chooses from a mixture of indistinguishable substances. Faint overtones, which would otherwise fail to be distinguished, are thus isolated and their pitch determined. "The proper tone of the resonator may even be sometimes heard cropping up in the whistling of the wind, the rattling of carriage-wheels, or the splashing of water." The proper tone of a resonator held to the ear during the playing of a piece of harmonised music, will be heard rising out of the mass in bold contrast.

By means of a series of such tuned resonators every note of the piano may be analysed or resolved into a number of separate tones; and it will be found that the lower tones are more complex than the higher.

Also on examining by these means the C sounded on the middle key of the piano, the same C sounded on a plate, a violin, a harmonium, &c., we should find that they all differ in one or more of three respects, namely :—

(1.) In the *number* of overtones present; or,
(2.) In the *order* of those present; or,
(3.) In their *relative intensities.*

The possible combinations of harmonics which may thus be created are practically infinite in number. It has been calculated that with six overtones and two shades of intensity for each, we may thus have more than 400 shades or qualities of tone.

The musical sounds of strings and stringed instruments.

529. The rate of vibration in strings increases with their *shortness*, *lightness*, and *tension:* for if a string be *long* or *heavy*, there is a greater mass of matter to be moved than in one short or light, and thence a slower motion; and if a string be slack, the force of elasticity which pulls it from any deviation back to the straight line will be so much the less. The facts are, that a string taken of half the length, or of one-fourth the weight, or of quadruple the tension of another string, vibrates just twice as fast on any one of these accounts; a string of one-third the length, or of one-ninth the weight, or of nine times the tension of another, vibrates three times as fast; and so on for other proportions.

These truths are familiarly illustrated in the violin. The low or bass string is thick and heavy, being covered with wire, and the others gradually diminish in magnitude and weight, up to the smallest or treble. The strings are tuned to each other by being attached by one end to movable pins, which, when turned, increase or diminish the tension; and the sound produced by each is afterwards varied to a certain extent by the performer pressing different parts of it with the finger against the board, so as to shorten or lengthen the vibrating portion.

An analogous law, as to the influence upon tone, of weight and dimensions, holds with respect to bells, glasses, reeds, &c.

530. If a long musical string be made to sound, and then only half of it be made to sound, as when a movable bridge is placed under the middle, or a finger presses it there, the half will sound the note which is the octave to the first, and will therefore vibrate twice as fast; and similarly the third part sounded, will give the fifth to the last-note, and will vibrate three times as fast as the first; a fourth part, four times as fast; and so on, producing the sounds or tones thus nearly related to each other. Thus, if by means of a bridge we divide the string into two parts whose lengths are in the ratio of any of the notes of the scale, we shall obtain the two notes by sounding the two parts of the string. It was in this way that the ancients discovered the simple numerical ratios connecting the different notes of the scale. The string of a violoncello, when made to vibrate by a bow moved very gently across it, near the bridge, often divides itself spontaneously into two, three, or four, &c., equal vibrating portions, with points of rest between them called *nodes*. When this happens, there are heard in succession, or even together, not only the sound or note belonging to the whole length of the string, but also, more feebly, the subordinate notes belonging to its half, third, or fourth, &c., that is the whole series of *harmonics* as explained above. Often in such a case the subordinate sounds swell with such force as to overpower for a time the fundamental note. The same harmonic sounds may be produced still more certainly, while drawing the bow across the string, by touching the string lightly with the finger or with a feather at one of the points where we wish it to divide. Even a varied air may be thus played by the harmonics only.

The sounds belonging to a single cord or string, and produced by its spontaneous division into different numbers of equal parts, constitute, when heard together or in succession, what may be called a simple music of nature herself. It is produced pleasingly, as just described, by the single string of a violoncello, but also in a very interesting manner by the instrument called the Æolian harp.

531. The *Æolian harp* is a long box or case of light wood, with harp or violin strings extended on its face. These are generally tuned in *unison* with each other, or to *the same pitch*, except one which is thicker than the others, and vibrates only half as fast, giving the lower octave to the others, and serving as a bass. When the harp is suspended among trees, or is placed in any situation where the fluctuating breeze may reach it, near a window partially opened, for instance, each string, according to the manner in which it receives the blast, sounds either entire, or breaks into some of the simple divisions above described; the result of which is the production of a pleasing succession of musically-related sounds. After a pause this fairy harp may be heard beginning with a low and solemn note, like the bass of distant music in the sky: the sound then swells as if coming near, and other tones break forth, mingling with the first, and with each other. In the combined and varying strain, sometimes one clear note predominates and sometimes another, as if single musicians alternately led the band: and the concert often seems to approach and again to recede, until with the unequal breeze it dies away, and all is hushed again.

532. It is to be remarked that the mere vibrations of the strings alone would be inaudible but for their connection with the extended surface of the box. The elastic wood is capable of taking up the vibrations of the strings, and by its broad surface throws a large mass of air into pulsations, and thus gives effect to the vibrations, or renders them audible. Hence the quality and value of all stringed instruments depend not on the strings, but on the proper adaptation of the elastic resonator to the production of their vibrations. In the piano, the harp, the violin, &c., everything depends on the perfect elasticity of the sounding-board.

533. The vibrations of strings fixed at their two ends may be experimentally studied by means of a long india-rubber tube, or a long spiral of fine brass wire, or even a long flexible rope.

First, on swinging the rope as in AA′ (fig. 153), we find that it executes its vibrations in a definite period, depending merely on the length and weight and elasticity of the rope or tube, or wire helix.

Next, on tilting up the end, A, sharply, we raise a hump or wave which will pass on to the other end, A′, in the same time as the whole string, AA′, takes to make one vibration.

As it cannot pass the end A′, the wave is reflected there, and returns towards A with its former motion reversed, till on arriving at A it is once more reflected, and passes on towards A′ as at first, these reflections continuing till at last all the motion is destroyed.

If now we tilt up half the rope, BB′, at one time, and keep tilting it at regular intervals, then, when the first wave is being reflected from B′, a second is just starting from B; these will obviously meet at N in the middle of the rope, and as this point is solicited in two opposite directions at once, it will remain at rest, and the string will in consequence keep vibrating as if each half were independent of the other. The point, N, is called a node; and the two bulging pieces of the string are termed *ventral segments.*

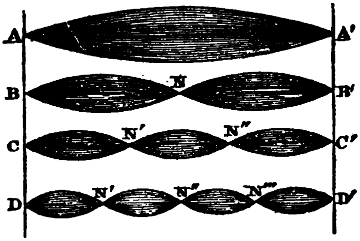

Fig. 153.

In like manner the string may, with a little care, be divided into three ventral segments, with two nodes, as in CC′; or into four ventral segments, with three nodes, as in DD′, the divisions being distinctly visible.

It is quite easy to throw a sounding string, such as a long string of cat-gut stretched over a sounding box, into ventral segments, by lightly touching with the finger, or with a feather, at some exact division, such as a fourth or a fifth of the whole string, and then sounding this part in the ordinary way with a fiddle-bow.

534. A simple method of shewing these ventral segments is to fasten a white silk or light cotton string to one prong of a tuning-fork, the tension of the string being regulated by weights, W, in a

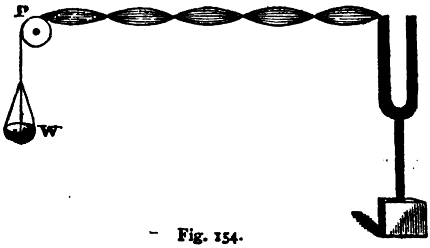

Fig. 154.

scale-pan attached to the end of the string (fig. 154). On sounding the tuning-fork with a bow, the cord is thrown into one or more segments as the case may be: and by reducing the tension to a half or a third, we increase the number of segments *four* or *nine* times. All the laws of vibrating strings may be thus experimentally established.

535. The simple scale of sound which nature thus gives by the spontaneous dividing of a single string, corresponds with the series of *harmonics*, as explained above, and is called a *chord.* The vacancies in it, compared with the common musical scale, may be filled up by joining to it the notes of two additional strings, one a third shorter, and therefore giving sounds sharper or more acute than it, and the other a third longer, and therefore giving tones more grave. Of these additional notes, while part agree, or are in unison with certain notes of the principal chord, the remainder just serve to fill up its larger intervals, and to complete a scale of nearly uniform interval—as three ladders, having unequal intervals between their steps, might still, if placed together, complete a stair of easy ascent. The relation between these strings or chords is such, that the principal beats thrice for twice of the low chord, and the high chord beats thrice for twice of the principal; and in the usual scale of notes, the principal is the fifth note above the lower and fifth note below the higher.

The numbers which express the relations of beats among the notes of an octave are easily found, from our knowing the relative number of beats in the notes of any one simple chord, and the relation as above described of the three chords forming the compound scale. The following table exhibits on the first line these relations, or the arithmetical expression for the beats of an octave; in the second line the corresponding lengths of a given string required to produce them; in the third line the English designation of the notes by letters, and in the fourth line the continental designation by names, these names being the first syllables of certain verses formerly sung by learners:—

Relations of vibrations	1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2
Length of string	1	$\frac{8}{9}$	$\frac{4}{5}$	$\frac{3}{4}$	$\frac{2}{3}$	$\frac{3}{5}$	$\frac{8}{15}$	$\frac{1}{2}$
English characters	C	D	E	F	G	A	B	C
Continental names...	ut	re	mi	fa	sol	la	si	ut

536. If the intervals in the musical scale were all equal, a performer might choose indifferently any note as a fundamental or *key* note, and would only have to attend to the number of intervals above and below it; but, in fact, the relation of the three constituent chords is such, that the third and seventh intervals in ascending from a key note are only about half as large as the others. It is owing to this circumstance that in *changing the key* on an instrument, certain notes belonging to other keys are about half a note too low or too high, that is, too *flat* or too *sharp*, and must be changed accordingly. And hence, when an instrument is to be used to play in all keys, its larger intervals must be divided into two parts at least. The fact of these unequal intervals, ill understood, is what gives an appearance of great complexity and difficulty to musical science.

537. *Melody*, in music, is when notes, having the simple numerical relations of beat which we have been describing, are played in succession: *harmony* is when two or more such notes are sounded together. The effect of both is delightfully increased by what is called *measure*, viz., making the duration of the notes or strain correspond with certain regular divisions of *time*. This gives to the listener an anticipation, to a certain degree, of what is coming, with the pleasure of having expectation realized, as happens similarly in regard to the metre and rhyme of poetry: it moreover enables the memory to retain musical combinations of sound. The airs of the Æolian harp, which observe no *time*, cannot be learned by rote or repeated. The music of a single drum is chiefly that of *time*.

The *accompaniment* of an air afforded to a singer by one or more instruments, and which is so pleasing, is chiefly the sounding simultaneously, in a subdued manner, some other notes of the chords to which the several vocal notes belong. *Duets* and more complicated *concert-pieces* have their origin from the same source: and highly cultivated musical sense can even follow and enjoy several melodies played together.

Musical notes, by whatever instrument produced, have to each other the same numerical relations in the beats or vibrations which constitute them. The different qualities of tone, therefore, from different instruments, can depend only on peculiarities of the single beats, as to whether they are sharp or soft, strong or weak, and accompanied or not by their natural harmonics. Such is the extraordinary nicety of perception which the human ear possesses in this respect, that it can not only distinguish different kinds of instruments, as a flute and clarionet, playing the same note, but with respect to the human voice, goes to the extent of recognizing almost each one of many voices singing the same air. One of the greatest charms of concert-music is that a particular voice and the different instruments may take up, separately, parts of the strain suited to their individual expression: the flute and hautboy, for instance, breathe softness; the trumpet and drum arouse; the harp rolls forth its brilliant chords; the violin leads the clear sound through rapid and endless variety; and so of the rest.

That there might be correspondence in instruments when played together, and a known pitch when played apart, it became necessary to fix on some tone or certain number of vibrations as a point of comparison. Hence tuning-forks are made of steel, with length of prongs calculated to produce a certain note (see Art. 536). This note is usually the fourth A or *la*, from the bass of the pianoforte, and vibrates about 440 times in the second;—and when the note of the same name on any instrument is *tuned* in unison with this, the other notes can be easily adjusted according to the harmonic relations above explained.

538. Almost every substance or contrivance that can produce a uniform continued sound may enter into the composition of a musical instrument: hence the almost endless variety which the world has seen. The chief classes of instruments are *stringed instruments*, *wind instruments*, and *bells* or *rods*.

The *guitar*, as affording an accompaniment to vocal music, has many advantages. It is not too loud, yet the strains are very distinct: it admits of most touching expression; command of it is easily learned to the extent desirable as an accompaniment, by any one who should attempt to perform music at all; it is portable and cheap. The great facility of accompaniment on it depends on this, that the player is able by one position of the hand so to touch the strings, that the sounds of all the six shall belong to the same chord:—three positions of the hand, therefore, for one key, produce all the notes and chords which a simple accompaniment requires; and the hand soon falls into these so readily, that the player is hardly sensible of exerting volition in regard to them.

Sounding Rods and Plates.

539. Rods of wood, metal, glass, &c., *fixed at both ends*, will vibrate and divide into ventral segments after the same manner as the strings above described: but the same simple relations between the pitch of the note produced and the number of segments do not obtain. When a string of catgut tightly stretched divides into two segments, each half sounds the octave to the note produced by the whole vibrating string; but when a rod thus divides into two, each half vibrates more than twice as fast as the whole, and hence the note sounded by each half, is higher than the octave to the prime or fundamental note of the rod; the reason being that the force tending to restore the rod to its position of rest or equilibrium, is greater than that in the case of the string.

If a steel or brass rod of two or three feet be fixed at one end only, and made to vibrate, either by striking or by means of a fiddle-bow, it will divide into wave-sections, like a sounding string. If the rod be three feet in length, it will vibrate about once in a second, and the motion will be plainly visible, but too slow to be audible. As we shorten the rod, the rapidity of quiver increases very fast; being *four*, *nine*, &c., times as fast when the length is reduced to a *half*, a *third*, &c. At about *four* inches, the vibrations begin to fuse together into a sound, and a steel rod one inch long will give nearly 1300 vibrations per second. An instrument to sound the notes of the gamut or scale might obviously be constructed out of eight rods whose lengths were connected by these relations. The metal tongues of the common musical-box belong to this class of sounding bodies.

540. The motions of the free end of a vibrating rod fixed at the other end are much more complicated than might at first be supposed: they may be easily followed by fixing on the end of the rod a common glass bead, silvered inside, and watching the fiery path which the bead will trace out in presence of a candle-flame or strong sunlight. By striking the rod at different places or in different ways, the luminous track may be made almost infinitely various: sometimes curves of exceeding beauty are obtained. This method of studying the vibrations of a rod by the rapid motion of a luminous point is the invention of the late Sir Charles Wheatstone.

The common *harmonica*, and the *claque-bois* of the French, consist of a series of glass, wood, or brass rods, graduated in lengths so as to give a musical sequence of notes, and laid loosely on two strings or rods.

541. The *tuning-fork* is simply a bent steel rod whose ends are free to vibrate, and whose constancy of vibration-period is insured by the stability of character which good-tempered steel possesses: so that it may at any moment be appealed to as a referee for the pitch of any required tone.

When a tuning-fork vibrates, each prong may divide into two or more ventral segments, just as a string or a straight rod may do. The deepest or fundamental tone is got when each prong sways to and fro as a whole: the first overtone or harmonic is got when each prong divides into two, the second when each divides into three, and so on. But, in accordance with the law already stated for vibrating rods, the first overtone is not the *octave* of the lowest or prime tone, but one which makes twenty-five vibrations while the first makes four. Thus the first overtone of a C fork, which makes 256 vibrations per second, will be a note making 1600 per second: and the others rise in the following proportions:—While the *first* overtone makes 9 vibrations, the second, third, fourth, &c., will make 25, 49, 81, &c. That is, the vibration-rates of the whole series of overtones are *as the squares of the successive odd numbers* 3, 5, 7, 9, &c. The vibrations of a tuning-fork may be readily shown by bringing it near to a light ball or a small bead suspended by a thread; the bead will be projected to a considerable distance.

"*Chladni's Sonorous Figures.*"

542. Plates of wood, glass, or metal may be made to give forth musical sounds like rods, by fixing them at one part with a clamp, or in a vice, and drawing a violin bow across the edge. The famous musician, Chladni, in 1785 discovered a simple method of rendering the vibrations of plates visible. He fixed the plates horizontally, and strewed some fine sand over them. On sounding the plates with a fiddle-bow, the sand was set in vibration and collected in regular heaps along the lines of no vibration, or the *nodal* lines, that is, the lines where parts of the plate in opposite states of vibration meet, or where the parts are at rest. In fig. 155 these nodal lines are seen in a variety of forms. The sand assumes the position indicated by the lines across the squares.

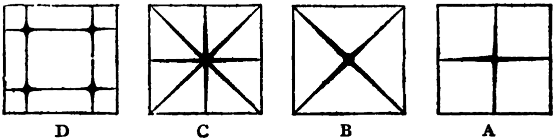

Fig 155.

A square metal or glass plate, firmly fixed to a metal or wooden rod at the centre, a violin bow, and some "silver sand," are all the apparatus required to produce these remarkable figures. When the bow is drawn down the edge of the plate near one corner, we get the lowest or fundamental note, and the sand collects in the two straight lines joining the middle points of the opposite sides, as in A. If we draw the bow down the middle of one side, while we lightly touch one corner, the sand heaps itself along the diagonals of the square, B, while the note given forth by the plate is a *fifth* higher than the former. With a few trials, drawing the bow across different parts of the edge of the plate, and touching other parts of the edge, so as to induce the formation of stationary lines, we may obtain an endless variety (C, D) of beautiful symmetrical patterns.

Some very interesting sonorous figures are obtained with round, three-cornered, &c., plates treated in the same way. A common hand-saw may be made to produce a figure appropriate to the note it gives forth.

As a bent rod becomes a tuning-fork, so a bent plate becomes a *bell*, or goblet, or glass, which is subject to the same laws of vibration as a plate.

If a bell-shaped glass, or a metal bell such as is used in the construction of clocks, be mounted mouth up, and some sand strewed inside, it will be found to arrange itself in *nodal lines* just as on the square plate, when we sound the bell with a fiddle bow. If water be poured inside, the surface will be thrown into ripples, separated by smooth furrows, according to a similar law.

A common tumbler or a finger-glass partly filled with water, or a large wine-glass partly filled with wine, may be made to sound, and throw the liquid surface into ripples by merely wetting the finger and moving it round the edge with some pressure. If the surface divides into *four* sections, then the deepest note of the glass is being sounded.

543. The sonorous vibrations of metal wires and rods, which we have just been detailing, take place transversely or across the line of their length. But they may also be made to sound by rubbing (with the wet, or resined, fingers) longitudinally, or in the line of their length. The laws of vibration are akin to those for cross-vibration; with half the length of wire or rod we obtain the octave to the original note; with one-third of the original length we get the fifth, and so on. The number of longitudinal vibrations per second increases in exact proportion as the wire or rod is shortened. It is to be remarked, however, that the longitudinal note given forth by any length of wire or rod is, as a general rule, much higher than the transversal note emitted by the same length; the reason being that the elastic force in the direction of the length is much greater than across the length, and the rapidity of vibration increases with increase of elasticity. When a short piece of wire is briskly rubbed the note is extremely piercing, almost painful.

Difference of *tension*, unless it be so great as to affect the molecular structure of the wire, does not alter the pitch of the sound; but different metals will for the same length of wire give different notes, simply because their degree of elasticity is different.

An iron wire, for example, gives a higher note than a brass wire of the same length and thickness, the elasticity being greater; and therefore the rapidity of vibration and the velocity of transmission of the sound pulse being correspondingly greater. Hence it follows that *by comparing the lengths of iron and brass wire which give the same note, we get the comparative rates of sound transmission through these metals.* We should find that an iron wire 23 feet long, and a brass wire 15½ feet long, would give the same note when we rub them with a wet cloth; and we conclude from this fact that sound travels through these metals in the same proportion, that is, in the proportion of 46 to 31. Thus, since in the former it is found to be about 17,000 feet per second, in the latter it is about 11,000 feet per second.

Similar experiments enable us to determine the comparative velocities of sound through different kinds of wood (see Art. 486). A glass, wooden, or metal rod fixed or clamped at one end, or clamped at the middle and left free at both ends, may be thrown into sonorous longitudinal vibrations, and obey somewhat similar laws. The longitudinal vibrations of a glass or wooden rod may be easily shown by experiment in the following way:—Fix the rod by one end in a vice or suitable wooden clamp, and hang against the free end a small bead or ball by means of a silk thread: on rubbing the rod lengthwise with the wet fingers or a resined cloth, the small bead will be shot away to a considerable distance.

Kundt's experiments.

544. A glass tube, closed at the ends, may be considered a hollow glass rod enclosing a rod of air. The wave-lengths of glass and of air will be very different; in other words, the lengths of a rod of glass and of air vibrating together or sounding the same note, will be proportioned to the velocities in glass and air respectively. Just as we obtained the comparative velocities of sound in iron and brass by comparing the lengths of iron and brass rods, which gave the same note, we have only to find what length of an air-rod vibrates in unison with any given length of glass rod to determine this relation. The invisible nature of air renders the direct comparison in this respect apparently impossible. But we owe to M. Kundt, of Berlin, a very simple solution of the difficulty.

A small quantity of lycopodium dust (the dust of the club-moss or puff-ball) is placed inside the tube, so as to line it through its whole length. This light powder reveals the condensations and rarefactions of the air within, when the tube is sounded by the wet fingers or a wet cloth. It collects into heaps, separated by clean spots, or spots of no vibration, corresponding to the nodes. The distance between any two nodes or spots of no vibration is, of course, half a pulse-length of the internal air; if the tube be fixed or clamped by its middle, the length of the tube is half the pulse-length of the fundamental note which it sounds; for the middle is a node, and each free end is the centre of a ventral segment, so that the two halves together only make the length of one ventral segment. Each of the short air-pulses is made in the same time as the tube itself takes to pulse, or lengthen and contract; and the length of a pulse is the distance travelled by the sound during the time of formation of the pulse. Thus, the velocity of sound in glass will be as many times greater than that in air as the number of dust heaps within the tube. This will be found to be *sixteen*, if the conditions of the experiment be properly attended to. If the velocity in air be 1120 feet per second, that in glass will be 16 times 1120 feet, or 17,920 feet, a little over 3⅓ miles per second.

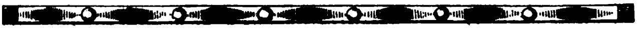

Fig. 156.

Other gases introduced within the tube will give a different number of dust heaps: carbonic acid gas will give twenty heaps instead of sixteen, while coal gas will only give ten heaps, and pure hydrogen about five heaps. These numbers represent the comparative velocities of sound through these gaseous media.

545. By an extension of the same experimental method the comparative velocities of sound in air and in metal rods may be readily found. A brass or iron rod, B D (fig. 157), has fitted at its middle, C, a cork which just fits the end of the glass tube, A C, and on the end, B, a cork which will pass through A C with very little friction, and the rod is fitted in the figure so that A B is of the same length

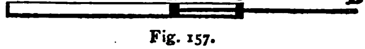

Fig. 157.

as B D. Some lycopodium powder is put into A B, and B D is made to sound by briskly rubbing with a resined cloth. The vibrations of the rod, B D, are communicated to the air-column, A B, by B acting as a piston. It divides itself into segments (shown by the lycopodium heaps) which vibrate in unison with the rod, B D. The number of these segments will give the number of times by which the velocity of sound in the brass rod, B D, exceeds that in air. Thus, *brass* gives a sound-velocity of nearly *eleven* times that in air; *steel*, 15⅓ times, and copper 12 times. The relative velocities of any solids capable of being formed into rods, may thus be determined.

Sounding air-columns; organ-pipes.

546. When we blow across the mouth of a pipe or tube, every one knows that by properly modulating the blast, a musical note is obtained; and the shorter the tube the harder we must blow to get it to sound. A railway whistle is a wide short tube, which only a powerful blast of steam can suffice to sound. In understanding the cause why a whistle sounds, we have to remember that an air-column of a given length and pressure takes a definite time to vibrate or pulse, just as a string of a given length or tension, or a pendulum of a given length takes a definite time to vibrate. Double, triple, &c., a length of air-column just takes double, triple, &c., time of vibration. When we blow against the edge of an organ-pipe we set up small pulses of the adjacent air; and when these have the same periodicity as the vibrations of the air-column, they induce pulsations of the latter which gradually swell into a sonorous scream.

When a tube is closed at one end, the theory of its vibrations is analogous to that of a vibrating rod fixed at one end; the closed end of the pipe, like the fixed end of the rod, forms a node, and the open end, like the free end of the rod, forms the middle of a ventral segment. For the lowest tone of such a pipe, then, its length must be just the fourth part of the pulse-length of that tone. By blowing harder we may obtain higher tones or overtones, but there will obviously be, in every instance, an odd half of a ventral segment. Thus, the number of vibrations being in proportion to the number of ventral segments, the pulse numbers of the lower and higher tones will stand in the relations of ½ to 1½, 2½, 3½, &c., that as 1 to 3, 5, 7, &c. This is easily confirmed by trial with different lengths of glass or metal tubing.

547. But, again, a pipe open at both ends will also give a musical note; it is like a rod fixed at the middle and free at both ends. Each end will be the middle of a ventral segment with a node between, and consequently the length of the pipe will be half the length of the corresponding sound-pulse.

Hence, if we blow at one end of a piece of glass tube, say six inches long, the length of sound-pulse generated will be twelve inches when the tube is open at both ends, but twenty-four inches when we stop one end with the finger. The ear will easily confirm this, by declaring the latter note to be an octave below the former. Hence, a 3-inch closed pipe would give the same note as a 6 inch open pipe.

548. It matters little how the air-pulses are set up in a tube or pipe. A tuning-fork, of the same pitch as the pipe, held at its mouth, will be enough to make the interior column resound the same note.

In an ordinary organ-pipe, the primitive action of the lips, which is employed in the flute, is replaced by the arrangement seen in the figure. The wind entering at *b* (fig. 158), issues in a flat sheet through the bass slit at *d*, and breaking into a flutter upon the edge, *e*, induces the pulsations proper to the air-column, *a*, in the pipe. The principle of a common whistle is very much the same; only in the whistle there is no cavity before the sheet formation of the air.

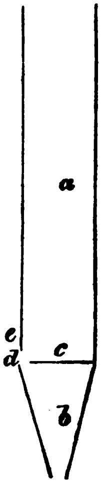

Fig. 158.

In what are called *reed-pipes*, an elastic flap, or valve, induces by its vibrations the sonorous pulsations of the tube. The notes of the clarionet, hautboy, and bassoon are thus created. In the child's trumpet, the French horn, the harmonium, concertina, &c., the elastic tongue does not thus act as a complete flap, but vibrates to and fro within the aperture, practically opening and shutting it, but not absolutely so. In any case the note will depend on the elasticity, length, stiffness, &c., of this governing vibrator. In the trumpet, trombone, cornet-a-piston, &c., the quivering of the lips takes the place of this elastic tongue of the reed. The fingering of a flute or whistle produces variations of pitch by simply varying the length of the vibrating pipe, or by altering the position of the internal nodes; for where a hole is opened the air inside the tube will be in the same condition as at the open end of the pipe—that is, will be the middle of a ventral segment. Thus, if a node was there when the hole was closed, it can no longer be there, and the note will be altered in pitch according to the rule already explained.

549. In large organs there are several thousands of pipes, with the mechanical means for enabling the organist to sound any single pipe by opening a valve so as to admit the wind to this pipe alone. In the organs in York Minster and in the Birmingham Town-hall there are 4200 and 3000 pipes respectively; and in some of the Continental organs there are as many as 5000 or even 6000 pipes. The pipes of an organ are divided into sets, each set being of one character or quality, and running through the full musical compass of the instrument; and when the organist draws any stop he merely brings the corresponding set of pipes under the control of his keys. In the York Minster organ there are 56 stops, and in the Birmingham organ, 40 stops. The deepest note is given by a 32-foot pipe, which will consequently send forth the sound-pulses 64 feet long, and, therefore, at the rate of 1120 ÷ 64, or about 17 per second; which, as we have seen, is the inferior limit of the musical scale.

550. The sounds of the human voice are the sweetest of all, and are produced on the reed-principle, by the vibrations of two delicate membranes situated at the top of the windpipe, called the *glottis*, with a slit or opening left between them, for the passage of the air, called *rima glottidis*, or chink of the glottis. The tones of the voice are grave or acute, according to the varying tension of these membranes, and to the size of the opening through which the air rushes.

Singing Flames.

551. It has been long known that when a jet of hydrogen is burnt with a low flame, and a long tube from one to two inches wide, and open at both ends, is held over the flame, musical sounds are produced. These vary in intensity according to the length and width of the tube and the thickness of the glass or material, and they are modified by raising or depressing the tube over the flame, or by holding above it other tubes of different dimensions. Narrow tubes produce a shrill, and wide tubes a grave, sound. At the time these sounds are produced, it will be observed that the hydrogen flame is lengthened, and burns with a rapidly vibratory movement. The gas, in fact, burns with a succession of small explosions, which succeed each other at regular intervals.*

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* On looking at the reflection of the flame in a mirror waved backwards and forwards by the hand we see not the continuous band of flame which is reflected when the tube is quiescent, but a row of separate luminous tongues. By causing a mirror to revolve with great rapidity before a hydrogen flame, Sir C. Wheatstone was able to demonstrate that the circular band of reflected light was unequal in width, while with an ordinary flame it was of equal width throughout.

The column of air in the tube is set in vibration, and sounds are produced, varying with its length and width. This has been called the *Chemical harmonicon*. Mr. Herschel has shown that these musical sounds are also produced by the combustion of coal gas in a tube above a layer of iron wire gauze, fixed at about one-third of its length. These flames not only produce sound, but are highly sensitive to sounds produced by other causes.

Thus, if a small gas flame be inclosed in a tube so as to be near the position at which it would make the tube sound, and if, with the mouth or a trumpet, the proper note of the tube be sounded, the inclosed air column will sympathise with the pulse and set the gas flame singing. We have thus seen one tube set off another which was brought near to it. These have been called singing flames. They depend on the vibration of columns of air in tubes (see Art. 546).

Musical Glasses.

552. Bells or goblets of glass sound still more perfectly than those of metal, and when, by gentle friction on their edges with the wetted finger, their tones are called forth, nothing can exceed them in softness and purity. These may be continued for any length of time, and may be made to swell and diminish like the human voice or the notes of the Æolian harp. A set of glasses, therefore, attuned to each other according to the harmonic scale, become, for certain kinds of music, a very perfect instrument. They form, in fact, an Æolian harp at command. Dr. Franklin, who first constructed a set, simply doubled the long line of glasses upon itself, making two rows, and placed the half-notes on the outside. The writer, during some experiments on sound, found the *zig-zag* arrangement here represented to possess some advantages. The small open circles in fig. 159 represent the mouths of the glasses standing in a box, *a b c*, and the relation of the glasses to the musical notes, as commonly written, is shewn by the five music lines and spaces which here connect them. The learner discovers immediately that one row of the glasses produces the notes written *upon* the lines, and the other row the notes written *between* the lines; and

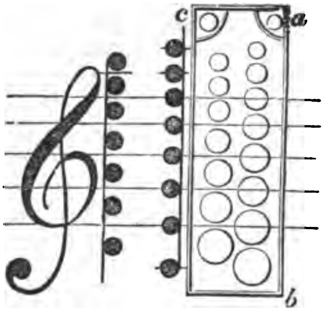

Fig. 159.

we can thus mentally command the instrument after a simple inspection. This arrangement also renders the performance easy, for the notes most commonly sounded in succession, are contiguous; and the usual relations of the notes forming a tune, are so obvious to the eye, that much of the theory of musical combination and accompaniment is easily explained. The set of glasses here represented has two octaves, and with the additional *flat seventh* and *fifteenth*, seen at *a* and *c*, which, when required, may be substituted for the corresponding glasses in the rows, it is capable of playing the greater part of the simple melodies. Other half-notes, if desired, might be placed in outside rows. The player stands at the side of the box between *a* and *b*, and has the notes ascending towards the right hand, as in a pianoforte.

The Animal Ear—The Sense of Hearing.

553. The Ear, which is so admirably adapted to perceive the evanescent tremblings of the air, has of course a structure in most exact relation to their nature, as now explained. The parts of the ear, and the progress of sound to the sentient or auditory nerve, may be simply sketched as follows :—

1st. There is external to the head a wide-mouthed tube or ear-trumpet, *a* (fig. 160), for catching and concentrating the waves of sound. This organ varies greatly in shape in man and animals, but in all cases it is so constructed as to collect and transmit to the auditory passage, *h*, the aërial undulations which produce sound. Those which reach the *concha*, *i*, or hollow part of the ear, just in front of the entrance to the auditory passage, are so collected and reflected as to enter it in larger numbers, and thus intensify the sound. In many animals the external ear is movable, so that they can direct it to the place from which the sound comes. This is remarkably seen in the mobility of the ears of the horse, which are tubular ear-trumpets. These can be moved at the will of the animal in various directions, the head remaining fixed. In man the ears are not movable, but by the voluntary movements of the head, either ear can be placed in a position to receive favourably the sound-waves. When these are in the direction of the axis of the auditory passage, they strike the membrane of the tympanum, *g* (fig. 160), directly, and with the greatest

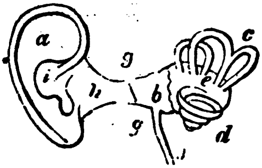

Fig. 160.

intensity. The tubular ear of the horse, which resembles a portable ear-trumpet, enables the animal to receive the vibrations in the most favourable manner for hearing, and he not only hears slight sounds, but can determine the direction in which they come. It is stated that, when horses or mules march in company at night, those in front direct their ears forwards; those in the rear, backwards; and those in the centre, laterally or across;—the whole troop seeming to be actuated by one feeling, which watches over the common safety.

The dog, the cat, the hare, rabbit, and squirrel, as well as many other animals, are provided with movable ears, more or less of a tubular shape, which enable them to hear and trace the direction of the slightest sounds.

2nd. The sound concentrated at the bottom of the ear-tube falls upon a membrane stretched obliquely across the channel, like the parchment of an ordinary drum, over the hollow space called the *tympanum* or *drum of the ear*, *b*, and causes this membrane to vibrate. This membrane is called the *membrana tympani* or membrane of the drum. Its situation is indicated by a dark line across the passage indicated by the letters, *g g*, in the figure. It completely closes the drum of the ear and cuts off all direct communication between the external atmosphere and the inner ear. It is placed in a slanting direction, forming an angle of 45°, with the lower surface or floor of the auditory passage, *h*, which is in consequence longer than the upper part or roof.

In order that this membrane may move freely in receiving the vibrations of air through the auditory passage, *h*, it is necessary that the air contained within the drum should have a direct communication with the external atmosphere. This is effected by the open passage, *f*, called the *Eustachian tube*, leading to the back of the mouth and opening into the throat. This tube serves to keep the air in the cavity of the tympanum of a uniform temperature and pressure, conditions necessary for the proper vibration of the membrane and the perception of sounds by the auditory nerve. The aperture of the tube in the throat is liable to be closed by a collection of the mucous secretion, or by a swelling of the membranes of the throat arising from an attack of cold. The temporary deafness which thence results, arises from the fact that the membrane of the tympanum can no longer freely vibrate. Sometimes the opening of the tube itself is plugged with mucus; and a crack or sudden noise, with an immediate return of the power of hearing, is generally experienced when, in the effort of sneezing, or otherwise, the obstruction is removed. If, when the tube is closed from any cause, the pressure of the external air is increased, the air in the tympanum cannot exert a proper degree of counter-pressure; the membrane will then be forced inwards and deafness will result. In descending in a diving-bell, the membrane of the tympanum is rendered very tense owing to the condensation of the external air, there is temporary deafness, and voices sound faintly. An undue tension of this membrane, which results from inequalities of pressure, is a frequent cause of deafness.

3rd. The vibrations of the membrane of the drum are conveyed farther inwards, across the cavity of the drum itself, by a chain of four small bones (not here represented on account of their minuteness), reaching from the centre of the membrane to the *oval door* or *window* (*fenestra ovalis*) leading into the labyrinth, *e*.

4th. The labyrinth, or inner compartment of the ear, over which the nerve of hearing is ramified, is full of an albuminous liquid; and therefore by the law of fluid pressure, when the force of the moving membrane of the drum, acting through the chain of bones, is made to compress this liquid, the pressure is felt instantly over the whole cavity, as in a hydrostatic press. The labyrinth itself is a cavity in the bone, completely shut off from the cavity of the tympanum, *b*, and it contains within it a membranous layer. Thus, what is called the *membranous* labyrinth supports all the minute ramifications of the auditory nerve, and being bathed on both sides with the liquid, it receives and transmits to the extremities of these nerves, the most delicate sonorous vibrations. It is this mechanical effect on the nervous fibres that produces, through the connection of the auditory nerve with the brain, the sensation of sound. The labyrinth consists of three distinct parts, the *vestibule*, *e*, the three *semicircular canals*, *c*, and a winding cavity resembling that of a snail-shell, thence called the *cochlea*, *d*.

The three canals and the cochlea also contain a membrane bathed with a fluid similar to that above described. The terminations of the auditory nerve are spread over this membrane, and equally receive and transmit the vibrations produced in the fluid. As the intensity with which sonorous undulations are communicated to a body, is proportionate to the extent of surface over which they can act upon it, it will be perceived that under this arrangement the auditory nerve is most favourably placed for receiving impressions, since it is spread over a large surface contained within a small space.

The vestibule is adapted to receive sounds conveyed through the external ear; but sonorous vibrations are also transmitted by the bones of the head, and these are better received by the cochlea than by the vestibule, owing to its peculiar form and its direct connection with the solid part of the bone.*

With respect to the semicircular canals, nothing certain is known of their functions. As they are at right angles to each other and, like the cochlea, so situated as to receive sounds directly through the bones of the head, it was supposed by the late Sir C. Wheatstone that they might enable a person to judge of the *direction* of sounds, as the fluid contained within them would be set in vibration with different degrees of intensity, according to the plane in which the sound was transmitted. Our perception of direction, however, is probably more connected with vibrations through the external ear than with those received through the bones of the head.

Among the common causes of deafness may be mentioned a thickening of the fluid of the labyrinth or of the membrane contained in it, or an obliteration of the canals. In most cases of congenital deafness these canals are found defective. This at any rate shows their importance to the function of hearing.

Perception of Sounds.—It has been stated that the human ear cannot perceive sounds when the number of vibrations is less than 32 or more than 18,000 in a second. Savart placed the limit for the highest sounds at 48,000 half vibrations, or 24,000 impulses in a second, and in reference to low or grave sounds, the ear could perceive those which were produced by 16 half vibrations or 8 impulses in a second. Other authorities have placed the extreme range of hearing of the highest sounds at 73,000 half vibrations the same period of time.

In this estimate an impulse is considered to be equivalent to a complete vibration.†

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* The power of the bones of the head to conduct sound may be fully appreciated by placing a musical-box, while playing, on the top of the head, and closing the auditory passages.

† Physicists do not agree in their conclusions on the range of hearing. The differences are partly due, as Professor Tyndall has pointed out, to the different meaning attached to the term "vibration." English and German authorities imply by this a complete vibration, *i.e.*, a motion to *and* fro. The French, on the other hand, limit this term to a semi- or half vibration, *i.e.*, a motion to *or* fro. On this subject the same authority states that if the vibrations are less than 16 in a second we are conscious only of the

The limits of hearing vary in different persons, and these are probably dependent on the state of the auditory nerve and the size of the membrane of the tympanum. Animals, in which this membrane is large, can hear much graver sounds than man. According to Dr. Wollaston the ordinary range of human hearing is comprised between the lowest notes of the organ and the highest known cry of insects. He found, however, that even in a healthy state of the ear, one person could not hear the chirping of a cricket, while another could not hear the chirping of a house-sparrow, and he met with several instances in which persons were unable to hear the piercing squeak of a bat.

Duration of Sounds.—As with vision, so with hearing, the sensation of sound lasts longer than the exciting cause of it. Savart found in his experiments on toothed wheels, that the removal of one tooth did not produce any interruption of the sound. A long-continued noise may be perceived for a short time after the cause of its production has ceased. Subjective sensations of sound, *i.e.*, impressions without any external cause for their production, generally indicate disease of the brain. These are equally heard with the auditory passages closed or open. Aural illusions are one of the most common features of incipient insanity.

Direction of Sounds.—The power of judging of the direction from which a sound issues, is not strictly connected with the sense of hearing. It is a mental operation based on experience. In listening, we acquire the habit of turning the head, and with it the ear, until it reaches a point at which the vibrations enter the passage by its axis, and the intensity and distinctness of the sound then produced, lead us to judge of the direction. The ticking of a watch held in a right line with the axis of the auditory passage may be heard at a distance of two feet, but when moved away a short distance on either side, and brought nearer to the head, the ticking will be no longer heard. A person in a thicket listening to the song of various birds, although they may be concealed from his eye by the luxuriance of foliage, can still judge correctly by the ear in

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separate shocks, and if they exceed 38,000 in a second the consciousness of sound ceases altogether. The range of the best ear covers 11 octaves, but the auditory range is sometimes limited to 6 or 7 octaves. The sounds available in music are produced by vibrations comprised between the limits of 40 and 4000 in a second. They embrace seven octaves.—'Synopsis of Lectures.'

what tree every little songster is concealed. One ear may receive the vibrations of a sounding body more strongly than the other. This would be in some degree a guide for the direction of the sound, but when the vibrations fall equally on both ears, as when the sound is equidistant in front or behind us, there is nothing by which the direction can be accurately determined.

The intensity of sound is to the ear in some degree a measure of *distance.* On a windy night the sound of a distant bell may be brought so quickly, that it has not yet had time to spread and be weakened; and a person is often roused from a reverie by its unusual loudness and apparent nearness. When a stormy wind blows directly upon a coast, and the swollen waves roll furiously upon the sandy beach or among the rocks, the countryman living many miles inland hears the uproar, almost as if the ocean had burst its barriers, and were pouring in upon the land. The scene-contrivers at our theatres heighten the illusion of an approaching procession by letting the accompanying music be first heard from a closed chamber or with very feeble tones, and afterwards with gradually increasing loudness. To the imagination, already excited by the suitable drama, the advancing host is thus most vividly portrayed; and when at last, with thunders of drums and trumpets from the front of the stage, the crowd also appears, the desired effect is complete.

In *ventriloquism* we have a remarkable illustration of the ease with which the ear is deceived not only in the direction, but in the distance of sound. A man by great skill may so imitate sounds as to make it appear that they issue from a box or a closet, or from behind a door, at different distances in an apartment. The sound, of course, is always seated in the ear, but it is inferred that it proceeds from a distinct body set in vibration.

PART IV.

GENERAL REMARKS ON HEAT, LIGHT, ELECTRICITY, AND MAGNETISM. THE MATERIAL AND DYNAMIC THEORIES.

554. The four subjects which will now require special notice, HEAT, LIGHT, ELECTRICITY, and MAGNETISM, were formerly classed under the head of Imponderable Substances. This name was assigned to them because there was nothing to show that they had weight or even a material existence. Recent researches have led to the hypothesis that these physical agents are but variously-masked forms of vibrations or undulations of an infinitely elastic *ether*, which pervades all space and penetrates even into the intimate molecular structure of all substances, solid, liquid, or gaseous. Undulatory or vortical movements of the particles of matter, varying in form and velocity, are transmitted to the ether, and through this to other particles, so that the atoms of matter and the ethereal medium are successively the recipients and the sources of motion. On this theory one definite kind of ethereal motion constitutes radiant HEAT; another, more rapid in its progress, LIGHT; and a third, differing from the preceding in form and character, produces the effects of ELECTRICITY and MAGNETISM. All physical phenomena produced by these agents are thus referred to one single mechanical cause, *viz.*, the transference of *motion*. This exposition of what has been called the *Dynamic theory*, is adopted by the most recent writers on physics.

555. Philosophers now incline to the opinion that there is at least one subtle fluid or medium occupying the wide space of the universe, and tending to equable diffusion, which fluid pervades denser substances somewhat as water pervades a sponge or loose sand, and that it has peculiar relations to each chemical element. They believe farther that physical phenomena, exhibiting sometimes the highest beauty, sometimes awful intensity and power, are dependent more or less on the motions of such fluid or fluids, somewhat as the sensation of *sound* in all its varieties, is produced in the delicate structure of the ear by modifications of motion in the air. Many philosophers until lately held the causes both of light and of heat to be material particles projected through space, somewhat as sand might be scattered by an explosion, such peculiar particles being present only when the effects were perceived; but now they hold the phenomena to be connected with vibratory motions in an elastic medium such as that above described.

We here refer to these hypotheses, not with the view of entering upon a detailed examination of their respective merits, or of asserting that either of them furnishes a complete explanation of all the facts, but merely to make the reader aware of the direction which inquirers' minds have taken in pursuing the investigation. The ascertained facts and laws of change important to be known to the general student, can be described and studied independently of such hypotheses.

556. The successive steps by which men have approached their present knowledge of the nature of heat have been nearly as follows :—

1st. Of old it was thought that sound was a subtle something which shot and spread around from sounding bodies and entered the ears of persons within a certain distance, producing the sensation called sound. It was in the course of time observed that bodies whilst sounding were generally in a state of visible tremor or vibration, like the lip of a bell or the string of a musical instrument; but until the time of Galileo it was not known that the air surrounding all things on earth is a material elastic fluid, having weight, inertia, and bulk like other kinds of ponderable matter, being capable, therefore, of receiving and conveying to a distance the tremors or minute vibrations of a sounding body, nearly as the surface of a pond into which a pebble is dropped, exhibits a succession of circular waves spreading from the spot where the stone falls to considerable distances around. The air might thus act as by a gentle touch on the delicate structure of the internal ear. A proof that such a supposition was well founded was afforded after the invention of the air-pump by experiments which have been elsewhere described (Art. 472). Other facts were soon observed, all proving the same truth—that the sound was conveyed by undulation of the air. Thus if two musical strings similarly stretched were placed not far from each other, the sounding vibration produced by the movement of one of them, was quickly produced also in the other, through the medium of the undulations of the air between them. It was then found that aërial undulations of sound striking against a smooth flat surface were turned back or reflected from that, so as to form what is called an echo, nearly as the waves of water in a pond having upright sides, are turned back or reflected by these.

2ndly. It was suspected that *Light* travelling freely through air, and still more readily through space deemed a vacuum, was an undulatory phenomenon of the same nature as sound, only taking place in a fluid still more subtle than air, and which pervaded space even to beyond the sun and stars,—a fluid without weight, but capable of affecting by its motion the extremely sensitive nerve called the retina, spread as a lining on the interior surface of the eye. As the undulations of water in a pond are reflected from the upright wall, and as the undulations of sound are reflected from smooth surfaces to form an echo, so, nearly, are the undulations of light in the supposed medium reflected from the surface of smooth mirrors. Many other close resemblances were noted between these different kinds of undulation, as will be shown in future pages.

3rdly. Then, as *Heat* is radiated from the sun and other luminous bodies like light, and in apparent union with it, having the same marvellous speed, and being reflected from surfaces exactly like light, so that its rays can be made to converge or diverge by mirrors and transparent lenses, and thereby to form burning-glasses and mirrors, it appeared highly probable that radiant heat was also of an undulatory nature, produced in the same or in a similarly diffused fluid.

557. Some of the important phenomena and effects of heat, such as the dilating, melting, vaporizing, &c., of ponderable substances of which the atoms may take on an undulatory condition, have not yet been fully explained, although they are generally believed to be consequences of the dynamic theory.

558. It will be shown in a future section on the phenomena of *Electricity* and *Magnetism*, that these are probably forms or modes of motion and action closely allied to those of light and heat; for both light and heat are produced with the highest intensity by electrical apparatus. Some physicists are prepared to admit that even the gravitation and inertia of ponderable matter, no causes of which have yet been plausibly conjectured, will be better understood when the nature of these physical agents is more fully ascertained.

Lastly, there may come from the same source a farther explanation of chemical action, crystallization, &c.

The object of this work, however, is not to deal with deep questions of causation yet unsettled, and which can interest only a small class of readers, but to give such a knowledge of important facts and laws as may befit the general student. Newton, by discovering the laws of gravitation which regulate the great phenomena of the universe, gave a great expansion to our knowledge, but he gave no insight into the occult cause of gravitation.

SECTION I.—HEAT.

ANALYSIS OF THE SECTION.

HEAT *is the sole cause of the difference between winter and summer, between tropical gardens and polar wastes. It cannot be exhibited apart, nor has it been proved to have weight, but the change of its amount in bodies is conveniently estimated by the concomitant change of their bulk; any substance so circumstanced as to allow this to be accurately measured, serving as a* THERMOMETER *or measurer of heat.*

Heat diffuses itself among neighbouring bodies until all have acquired the same temperature, that is, until all similarly affect a thermometer. Its inferior degrees are denoted by the negative term COLD. *It spreads partly through their structure, or by* CONDUCTION, *as it is called, with a progress, different for different substances, and which in fluids is quickened and modified by the motion or circulation of their particles; and it spreads partly also by* RADIATION *or by being shot like light from one body to another, through transparent media or open space, with a readiness influenced by the material and state of the giving and receiving surfaces.*

Heat, by entering bodies, expands them, and through a range which includes, as three successive stages, the forms of SOLID, LIQUID, *and* AIR *or* GAS; *becoming thus in nature, the grand antagonist and modifier of that attraction which holds corporeal particles together, and which, if acting alone, would reduce the whole material universe to one solid lifeless mass. Each particular substance, however, according to the nature, proximity, &c., of its ultimate particles, takes a certain quantity of heat (said to mark its* CAPACITY), *to produce in it a given change of temperature or calorific tension; undergoing* EXPANSION *in a degree proper to itself, and changing its form to liquid and to vapour or gas at points of temperature proper to itself.*

Such expansion in bodies generally increases more rapidly than the temperature, the cohesion of their particles diminishing with the increase of distance. Expansion is greater therefore in liquids than in solids, and in gases than in liquids; and the rate of expansion is quickened as the bodies approach the points of changing their form from liquid into gas. To produce these two changes, a large quantity of heat enters them; but in the new arrangement of particles and generally increased volume of the mass, it becomes hidden from the thermometer, or is no longer indicated by this instrument, and is therefore called LATENT HEAT. *For any given sub-*

stance the changes of form happen so constantly at the same temperature, that they mark fixed points *in the general scale of temperature, and enable men to regulate and compare thermometers. Heat, by changing the forms of different substances at different temperatures, influences much their chemical combination. Heat greatly influences the functions of vegetable and animal life.*

The great source of heat is the SUN ; *but man has gradually learned, by combustion, electricity, and other means, to command heat in other ways.*

" Heat is the sole cause of the difference between summer and winter, between the luxuriance of the tropics and barren wastes of the Polar regions. It is the sustainer of all vitality on the earth."

559. In the warm and temperate climates of the earth, its surface affords a delightful abode for men and animals, supplying all their wants and desires ; but when winter comes with a temperature below the freezing point of water, the scene is entirely changed. Then the earth with its waters is soon bound up in snow and ice, the trees and shrubs become leafless, appearing everywhere like withered skeletons,—countless multitudes of living creatures, owing either to the bitter cold or deficiency of food, perish in the snows, and nature seems dying or dead. The reverse change takes place when spring returns, that is, when heat returns. The earth is again uncovered and soft, the rivers flow, and warm showers foster vegetation, which soon covers the ground. Man, lately inactive, is recalled to many duties ; his water-wheels are everywhere at work, his boats are again on the canals and streams, his busy fleets of industry are along the shores :—winged life in new multitudes fills the sky, finny life similarly fills the waters, and every spot of earth teems with vitality. Many persons regard these changes of season, as if they came like the successive positions of the hands of a clock ; not considering that it is the single circumstance of change of temperature which effects these transformations. But if the colds of winter arrive too early, they unfailingly produce the wintry scene, and if warmth come before its time in spring, it expands the bud and the blossom, which a return of frost will surely destroy. A seed sown in an ice-house never awakens to life.

560. Again, as regards climates, there is a strong contrast between the aspects of nature at the equator and near the poles.

This is owing entirely to the great inequality of temperature which is permanent in those parts of our globe. Where heat abounds, we have the magnificent scene of uninterrupted tropical fertility: the earth everywhere covered with luxuriant vegetation in much greater variety than the milder temperate regions can show, in the midst of which, animal forms are equally abundant, many of the species having surpassing beauty, as birds, for instance, with plumage as brilliant as the gayest flowers. Again, where heat is permanently absent, there is the dreary spectacle of polar barrenness, bare rock or mountain, when not covered with snow or ice, instead of fertile fields; no rain, nor cloud, nor dew; vegetable life scarcely existing, and but of a lowly form in some sheltered spots facing the sun. In the winter of these climates, during which the sun does not rise above the horizon for nearly six months, unbroken darkness and silence, which are added to the severe cold, benumb all life. Into such a scene civilized man may penetrate from more favoured climes, but he can only leave his protecting ship and fires for short periods, nearly as he might issue from a diving-bell at the bottom of the sea. While winter, then, or the temporary absence of heat, may be called the sleep of nature, the permanent torpor about the poles is more like its death. Truly, therefore, may *heat*, the subject of our present chapter, be considered as the sustainer of life in the universe.

"*Heat and Temperature. Heat is not a substance, for it cannot be exhibited apart, nor has it been proved to have weight. Nature of Heat.*"

561. Heat and temperature are frequently used as if they were synonymous terms. *Heat* is that condition which excites in us the sensation of warmth. It exists in all bodies, even in those which convey the sensation of cold. *Temperature* implies the state of a body with regard to heat or cold, and its measurement by a thermometer. Mercury and oil may have the same temperature of 60°, as indicated by their producing the same rise in the thermometer, but the mercury will feel cold and the oil comparatively warm. The temperature of a body does not indicate the absolute quantity of heat contained in it, since we have not yet been able to fix upon the absolute zero of cold or the entire absence of heat. But the thermometer does not even show the relative quantity existing in the same body. A thermometer will indicate the same temperature (60°) in an ounce or gallon of water, although the latter must contain 160 times as much heat as the former.

562. Although heat is known to be abundant in the sunbeam, and to radiate copiously from a blazing fire, we cannot arrest or detect it in its progress except by allowing it to enter, and remain, in some ponderable substance. We know hot iron, hot water, or hot air, but nature nowhere presents to us, nor has art succeeded in exhibiting to us, heat alone.

If we balance a quantity of ice in a delicate weigh-beam, guarded against air-currents, and then leave it to melt, the equilibrium will not be in the slightest degree disturbed. Or if we substitute for the ice, boiling water or red-hot iron, and leave these to cool, there will be no difference in the result. If we place a pound of mercury in one scale of the balance, and a pound of water in the other, and then either heat or cool both through the same number of degrees, although (as will be explained below) about thirty times more heat enters or leaves the bulky water than the dense mercury, the two substances will still remain perfectly equipoised.*

Again, a broad sunbeam, with its intense light and heat, may be concentrated by a powerful lens or mirror, and be made to fall upon the scale of a most delicate balance placed in a vacuum, but will produce no depressing effect on the scale, such as would follow if what constitutes the beam had the least weight or momentum forwards.

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* These facts appear to show that the presence of heat in a body cannot be determined by the most delicate balance. The same may be said of electricity, for a Leyden jar charged with electricity, sufficient to destroy the life of an animal, weighs no more than it did before it received the electricity.

In describing these and other forms of matter as *imponderable*, we must not overlook the fact that our means of determining the presence of matter by gravitation are still very imperfect. The most delicate balance will not with certainty indicate the presence of a smaller quantity than the thousandth part of a grain. The mote in a sunbeam is imponderable, but it is still visible and material. Professor Tyndall has lately shown by experiments that these motes can only be detected in the atmosphere by passing through a closed glass vessel containing air, a powerful beam of light in a darkened room. Light is therefore a more delicate test of the presence of matter than any balance yet constructed.

A grain of matter may be split into a million or a billion of parts (see Art. 2), and thus rendered imponderable. Sir Humphry Davy long ago observed that if heat was as much lighter than hydrogen, as hydrogen is lighter than platinum, *i.e.*, bulk for bulk, 230,000 times, it would be far beyond the reach of any balance, although it might still be material.

Such were among the facts which led modern physicists to reject the old material theory or separate existence of a matter of heat called *caloric*, and to hold heat to be merely motion of a certain kind among the material particles of bodies.

"The Radiometer."

563. The crucial character of this test of the materiality of heat disappears, however, in the face of more delicate modern experiments, especially the recent experiments of Mr. Crookes on the "attraction and repulsion resulting from radiation."

Mr. Crookes suspends a fine glass stem, with a sphere or disc of pith, or paper, or metallic foil at each end, by means of a single cocoon fibre, inside a glass bulb of three inches diameter blown at the end of a glass tube eighteen inches long. By means of a Sprengel mercury pump (see Art. 468) the air is exhausted from within the tube and bulb with the greatest possible perfection. Strange to say, a beam of sunlight has a most powerful effect on this tiny balance; not only so, but the mere heat of the finger, or of a candle, impinging upon either disc, suffices to wheel it round through a quarter of a turn or more.

With a large apparatus of the same kind, and a pith bar suspended, a lighted candle placed about two inches from the globe causes the pith bar to oscillate to and fro, and then to make, as by cumulation of the heating effect, several complete revolutions, till the twist of the suspending fibre stops the rotation and finally reverses it; and this movement is kept up with great energy and regularity as long as the candle burns.

The action of a piece of ice or other source of cold is the reverse of this, causing the index to follow the block of ice as a needle follows a magnet.

Mr. Crookes has also suspended a lump of magnesium by means of a fine platinum wire within a long tube, so as to form a pendulum 39·14 inches in length (a seconds' pendulum). On making a very good vacuum within the tube, he has found that a ray of sunlight allowed to fall once on the pendulum and then cut off, is sufficient to set it swinging.

Several other forms have been given to the apparatus, but the principle is much the same in all, and the results are quite uniform in their character if the vacuum is perfect. When air or any gas is admitted the results are gradually modified, attraction in air taking the place of repulsion *in vacuo*. The barometric position or the density of the gas, at the neutral point which divides attraction from repulsion, seems to vary with the density of the disc on which the radiation falls, and on other physical conditions, which Mr. Crookes has investigated. He "is inclined to believe that the true action of radiation is repulsion at any pressure, and that the attraction observed when the rarefaction is below the neutral point is caused by some modifying circumstances connected with the surrounding gas, but not of the nature of air currents.

The sensitiveness of this apparatus is extraordinary, being much superior to that of an ordinary thermometric pile.

It remains for future experiments in the same direction to prove whether bare luminosity, apart from any heating rays, has such a sensible effect. Mr. Crookes' experiments seem to show that heat-rays act with the same effect on white or black pith discs, but that luminous rays sifted out from their heating companions have a different action and seem to repel black surfaces more than white. Taking advantage of this fact, he has constructed an instrument of extreme interest and delicacy which he calls a *radiometer*. It consists simply of four arms suspended on a steel pivot, and rotating horizontally like a miniature wind-gauge, with pith discs at the ends of the four arms, painted black on one side, the black sides all facing one way. The whole is enclosed in a glass tube from which the air is exhausted to the highest attainable degree, the tube being then hermetically sealed.

The mere light of a candle at a distance of one or two feet causes the arms of such an apparatus to rotate slowly, while the speed increases proportionally by reducing the distance, according to the well-known law of luminous intensity, being fourfold for half the distance, &c.; or the speed increases by keeping the light at the same distance and adding more candles. In full daylight the arms keep up a constant rotation at the rate of from thirty to forty turns per minute; while in full sunshine the rate increases to three or four turns per second, or even more, according to the lightness and delicacy of the individual radiometer.

Mr. Crookes, in assigning this mechanical effect to the radiant force or ethereal momentum, has estimated that a candle at a distance of six inches has a mechanical effect equal to ·00172 grain. Experimenting on the strength of solar radiation, Mr. Crookes makes out its mechanical effect to be equal to 32 grains on the square foot, or

57 tons on the square mile, or three billion tons on the whole earth, —a force which, but for gravitation, would drive our globe into space.*

Mr. Cunnington has shown by various experiments that heat, and not light, is most probably the motive power,† as in the experiments above described. Admitting this statement, modern physicists look upon light and radiant heat as similar forces, differing only in the number of vibrations.

"*Heat a form of Energy.*"

564. In another part of this work a place was assigned to Heat among *forms of energy*, thereby virtually removing it from a classification among *substances;* it now remains to explain more fully the reasons for stating, and the real meaning of the statement, that "Heat is a mode of motion," or rather of energy.

Bacon, among his keen-sighted aphorisms in his *Novum Organum* asserts that "heat is a species of the genus motion," that it is not merely a result of motion, but is in its essence motion and nothing else. Apart, however, from experimental proof, the speculative reasonings of even such an acute mind as that of Bacon are comparatively valueless. *Experiment* is the only sure foundation upon which to build our arguments as to the causes of natural phenomena. We shall, therefore, give a short account of the experimental *data*, to accord with which the only reasonable hypothesis is that heat is a form of energy.

In 1798 there was read before the Royal Society, by Count Rumford, an essay on the generation of heat by friction, in which it was contended that heat could not be a substance or material, but was in all probability motion. He was led to the conclusion by the results of a number of experiments he had made, which had been suggested by his observation of the very intense heat generated by the boring of cannon in the arsenal at Munich. His most important experiment was made with a hollow cylinder like a cannon, having a blunt steel borer which pressed against the bottom, the cylinder being turned round the borer by two horses. The cylinder turned water-tight in the centre of a deal box containing about 2½ gallons of water: at starting, the temperature of the apparatus and the water was 60°F. Exactly at the end of 2½ hours, the water was actually raised to the *boiling point* by the heat generated by friction against the borer. Calculating the amount of heat produced in the metal cylinder and borer, and adding this to that produced in the liquid, Count Rumford concluded that by converting into friction the motion of two horses, turning for 2½ hours, sufficient heat had been generated to raise the temperature of 26½ lbs. of water from the freezing to the boiling point. A constant stream of heat had thus been given out in all directions without any signs of exhaustion, and it was altogether incomprehensible that a limited mass could be capable of evolving an inexhaustible supply of any material substance, or of anything else than *motion* supplied to it from some other inexhaustible source of motion.

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* Proc. R. S.,' April, 1875-6.

† 'Pop. Science Review,' April, 1876.

The explanation of this production of heat by friction given by those who, under the name *caloric*, regarded heat as a substance, was that abrasion lessened the capacity of bodies for heat, and so liberated the heat which lay concealed in the intermolecular spaces of the unabraded mass. Experiment, however, proves that the capacity of a body for heat remains the same, whether it be in mass or in powder; in other words, that a pound of solid copper and a pound of copper dust thrown (at a temperature of 60° F.) into a pound of boiling water, absorb the same amount of heat from the water or diminish its temperature by the very same amount.

Sir Humphry Davy demonstrated the inconsistency of this hypothesis of latent heat by showing that water, with double the capacity for heat compared with that of ice, can be generated from ice by merely rubbing two ice-blocks together at a temperature below 32° in vacuo—an incontestable proof that the molecular excitement due to the *friction* is the sole cause of the difference between the liquid and the solid forms of water.

565. In every case of friction, of percussion, or of compression, heat is produced in greater or less quantity according to the mechanical force expended; and the simple and most reasonable interpretation of the fact is, that the sensible heat generated, is merely the transference of the *molar* or *locomotive* motion to the *molecules* of the body, in which it may be conceived to exist as an exceedingly rapid vibration, or non-locomotive motion, which is revealed to us as temperature by the thermometer.

It has been proved further, that *an exact relation* holds between the amount of heat generated and the amount of mechanical force expended in producing it There are many difficulties surrounding the experimental determination of this relation. In the first place only simple mechanical means must be employed, such as are capable of easy expression and measurement; and, secondly, it must be so arranged that the expenditure of all the moving force on friction, percussion, &c., be at the spot where it is wanted, or in the vessel into which the motion is to be poured for measurement.

“ *The great natural source of heat to this earth is the Sun.*”

Solar heat.

566. Without the heat received from this luminary neither animal nor vegetable life could be sustained. Human art can now, by concave mirrors or convex lenses, gather the sunbeams together, so as to produce intense heat in the focus of their meeting. A surface of glass, or any other small mirror, will so reflect the sun's rays as strongly to affect the eye at a distance even of miles; and that the heat accompanies the light is shown by the fact that many mirrors directed towards one point heat intensely. Archimedes is said to have set fire to Roman ships besieging Syracuse, by sun-beams thus converged from many points to one. When the light of a very broad sunbeam is made by a convex glass or lens to converge accurately to one narrow focus, the concentrated heat is sufficient to cause a piece of fusible metal held in the focus to drop like melting wax. Persons, wherever the sun can be seen may conveniently light their fires at the sun, by directing his energies through a burning-glass of sufficient power; and it is by an experiment of this kind that we may estimate the amount of heat which falls upon a given surface of the earth. A lens, two inches and a half in diameter, with a focus of about six inches where receiving the direct rays of a summer's sun, fires gunpowder in a second. The heat required for this is 545°. As a lens does not in any way augment, but merely concentrates the solar rays to a point, its area will correspond to the terrestrial surface which would receive this amount of heat. The area of such a lens would represent about five square inches, and thus it follows, by a simple calculation, that a square foot of the earth's surface would receive nearly twenty-nine times the quantity above mentioned. Faraday has made the curious calculation that the average amount of heat radiated in a summer's day upon each acre of land in the latitude of London is not less than that which would be emitted by the combustion of six tons of coals.

Lenses of large dimensions have been formed which have so concentrated solar heat in vessels containing oxygen, as to bring iron, charcoal, and even the diamond, to full redness and cause their rapid combustion. It is found that a heat of about 1200° is required to produce these chemical effects.

567. It is a remarkable fact that in these experiments the lens is not warmed, nor is the atmosphere which the heat-rays traverse, provided it be perfectly clear and transparent. Thus a double convex lens of transparent ice will equally concentrate the rays of heat radiated from the sun without absorbing them, and cause the ignition of phosphorus, a substance which requires a temperature of at least 113° for its ignition in air. The writer has witnessed this experiment as it was performed by Faraday at the Royal Institution. By that ingenuity so characteristic of that great master of science, he made the lens from Wenham ice in a few minutes, and the sun being favourable, used it for the ignition of phosphorus, the burning of paper, &c.

As further illustrations of this fact it may be mentioned that, although gun-cotton may be exploded by a heat of about 300°, the same focus of heat-rays which would explode instantaneously gunpowder, &c., will traverse the transparent fibres of gun-cotton without causing ignition until after the lapse of some time. The gunpowder being black absorbs the heat-rays readily. The same focus of rays concentrated in ether contained in a thin glass tube, traverses this volatile and inflammable liquid without heating it, although its boiling point is so low as 96°. If a small quantity of charcoal is added to it, the heat is absorbed, and the ether begins to boil immediately.

568. Reflection on such facts as these, and on the globular form and changing positions of our earth in relation to the sun, will lead to a clear explanation and measure of the differences of climate and of season found in different parts of the earth. All understand that if a small globe be suspended before a fire, the part which is nearest to the fire and receives the rays directly, will be much more heated than the other parts receiving the rays more or less obliquely. So on this earth, which is rotating before the sun, the regions about the equator are the most heated. The sunny side of many a steep hill in England receives the sun's rays in summer as perpendicularly as the plains about the equator; but such hill-sides are not heated like those plains, because the air over them is colder—as very elevated mountain tops, even at the equator, owing to the rarified, and, therefore, cold, air always around them, remain permanently hooded in snow. In England, at the time of the equinoxes, a level plain receives only about half as much of the sun's light and heat as an equal extent of level surface near the equator; and in the short days of winter, when the beams fall more obliquely, it receives less than a third part of the summer amount.

569. A picture has been designed to assist a student in conceiving clearly the consequences of the different intensities of the sun's influence in different latitudes on the earth. It is an elongated landscape of a strip of the earth's surface, stretching from the equator to the pole, exhibiting the more remarkable objects belonging to the vegetable and animal kingdoms peculiar to the different latitudes. At the equatorial end of this representation appear, amidst the endless variety of broad-leaved palms, such animals as the elephant, tiger, parrot, etc., and men as naked savages, or as the civilized Hindoos, seeking the shade of bungalows with darkened windows, and wetted mats hung round the walls to cool them. Corresponding views are given of the intermediate temperate climates, until at the polar extremity appear the dwellers in barren Greenland or Iceland, where the thermometer stands below zero, and the people are clothed in thick furs of polar animals, and protected by close artificially-warmed huts. Then one may reflect that all the contrasts here referred to, are in existence on the earth at the same moment of time.

570. An interesting evidence of solar influence on our globe is the periodical migration of animals which have their home not in any fixed region on earth, but wherever the sun has for the time the particular degree of influence best suiting them, and which accordingly follow the sun in the changes of season. In England, for instance, we have the swallow in vast numbers coming to visit our isles in the spring, to play over our woods and waters in pursuit of the insects which the heat then breeds to fill the air; and in autumn the same creatures are seen congregating on the shores, to wing their flight in united multitudes back to more southern countries, where, in turn, they find the needed warmth. The same season brings the cuckoo, the nightingale, and many other winged species In the waters of the bays and coasts, too, there appear in their seasons vast shoals of the finny races—the herring, the mackerel, and the beautiful salmon, which last, at stated times, penetrates from the ocean far up the mountain streams, to deposit its spawn in suitable localities.

571. Some animals which do not migrate, and which would be unable to resist the cold of winter, pass into a state of apparent death, which is called *hybernation*. The dormouse, the bat, and the marmot, or mountain rat, furnish instances of hybernation as a result of the withdrawal of solar heat. It has been proved that in these animals the vital functions are not arrested, but simply reduced to their lowest ebb. In the active state of the marmot, the pulsations of the heart are ninety in a minute. In the torpid or hybernating state they are reduced to eight or ten. Such are the effects of solar heat upon living animals.

572. *What is the source of Solar heat?*—Seeing that the experiments of Rumford and Davy have demonstrated on a small scale that molar motion, or the motion of masses, is a source of heat (Art. 563), some physicists have endeavoured to account for the enormous amount of solar heat shed over the globe on similar mechanical principles. The difficulties of this problem may be estimated when we consider that spectral analysis proves that iron and other fixed metals exist in vapour in the photosphere surrounding the sun, that an artificial heat of nearly 3000° is required to bring iron to a fluid state, and that the most intense heat which man can apply has failed to vaporize the metal. Dr. Mayer has endeavoured to solve this problem. Assuming that heat is in all cases derived from matter in motion, he has suggested that meteorites having an intense velocity from solar attraction, are continuously falling upon the surface of the sun, and that their suddenly arrested motion is converted into that which we call solar heat. Further, it is assumed that if the earth were suddenly stopped in its course and drawn into the sun by gravitation, the heat generated by the collision would suffice to convert into vapour the earth itself and all that was upon it. This ingenious hypothesis would, however, involve the necessity for an unlimited supply of meteorites, of the existence of which there is no evidence. Thus, in removing one difficulty this hypothesis would create another.

There is no reason to believe that the heat of the sun is derived from anything analogous to combustion on the earth, or that it is a product of chemical changes among the elements from which light and heat result. Angström detected in the photosphere of this luminary by spectro-telescopic observation, the vapours of thirteen metals, including those of iron and aluminium. It is remarkable that no lines indicative of oxygen, the most abundant element of our earth, could be detected. Delarue, on the occasion of the eclipse a few years since, was able to detect and measure the incandescent hydrogen emitted from the edge of the sun's disc; and he calculated that it rose to the height of from sixty to eighty thousand miles above the photosphere. Spectral examination clearly proves that neither the hydrogen nor the metals are in a state of combustion or oxidation. They are simply incandescent, or in the form of glowing vapours intensely heated, but remaining unchanged, or in their elementary state. By what form of energy they are maintained in this state it is impossible at present to speculate. All that we are entitled to say at present is that neither the theory of motion nor of chemical combustion affords any satisfactory explanation of the source of solar heat.

573. *Terrestrial Heat—Physics of the Earth.*—Although there are certain facts which show that the interior of our globe below a certain depth is in a heated state, there is nothing to indicate that any of this heat is transmitted to the surface, or that it affects the atmosphere above it. At a certain depth below the surface of the ground, the thermometer undergoes no change (see Art. 599). Below this, it is observed to rise gradually, and in a degree proportioned to the depth at which the observation is made. This statement rests upon experiments carried on in deep mines, and in artificial borings through the soil, as well as on observations of the temperature of the waters of *Artesian wells* and *Thermal springs.* It may be stated generally that in English mines at a depth of from 1500 to 1800 feet, the temperature at all periods of the year has been found to be from 70° to 80°. In one of the most recent borings for coal in Sussex (1875)*, at a depth of 1640 feet, the thermometer was found to stand at 72°.

Among Artesian wells may be mentioned that of Grenelle, in Paris, the depth of which from the surface is 1794 feet,—the temperature of the water is 82°. In the well of Mondorf, in Germany, which has a depth of 2202 feet, the temperature of the water is 93°.

The high temperature of Thermal springs also proves that there are sources of great heat in the interior of the earth itself quite irrespective of solar influence. The temperature of the water as it issues in some localities, as in Iceland and South America, reaches the boiling point, 212°. In the Pyrenees some have a temperature of 152°; in Auvergne they vary from 113° to 176°. The hottest in England is at Bath, of which the temperature is 117°, *i.e.*, 67° higher than the mean temperature of the place.

574. In considering the physics of the earth, we must notice not only the temperature, but other circumstances,—the discharge of thousands of gallons of water daily from some of these springs, the water being equally heated, and the flow of it continuing uninterruptedly for centuries.* The water rises spontaneously, and in thermal springs the power which brings it to the surface is, according to Buff and Bunsen, the pressure of steam produced below by intense heat. At 509° steam has an elasticity equal to fifty atmospheres, and it would sustain a pressure of a water column 1700 feet in height. It is, in fact, in the condition of superheated steam, and would have the power necessary to lift up the liquid column pressing upon it. As it reached the surface it would pass to the temperature of 212°, or lower. This view is confirmed by the observations of Bunsen on the Geyser springs in Iceland. At a depth of 62 feet below the surface, the water column, during the interval between two following discharges of the Geyser, has been found to have a temperature of 261°; at 47 feet, 253°; at 32 feet, 248°; at 16 feet, 223°; and at the surface, 185°.

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* The Subwealden Exploration.

575. Of the evidence furnished by volcanoes nothing need be said. We have in these ample proofs of the existence of an intense heat in the fusion of such a substance as lava, and its ejection in the molten state. Volcanoes are found active from Iceland to the Antarctic regions, and in the extinct state in great numbers over the whole of the globe. The lava which is thrown up appears to be very similar in composition in all parts, and the phenomena attending an eruption are the same. These facts appear to show a common cause, a common source, and they point to a common origin at great depths below the surface. They serve as terrestrial pyrometers.

All calculations regarding the amount of heat in the substance of the earth can be only approximate. Professor Buff, of Giessen, has estimated that the increase of heat in the earth's crust, below the stratum at which solar influence is observed to penetrate, amounts to 1·8° Fahrenheit for every hundred feet of depth. On this datum, he says, at a depth of ten thousand feet we should find a temperature at which water would boil, and at 120,000 feet, *i.e.*, about twenty-three miles below the surface, and only $\frac{1}{160}$th of the earth's radius, there would be a heat of nearly 2200° Fahrenheit, at which cast-iron melts and basalt runs like water.

Graham, relying on the experiments of Cordier, assigns an increase of one degree for every fifteen yards below the invariable stratum, equivalent to 116° for each mile. Admitting this rate of increase, we should have in a depth of about 30 miles, a temperature of 3580°, sufficient to render malleable iron fusible. From the very slight extent to which the crust of the earth has been penetrated we are bound to speak cautiously on this subject. The deepest mine, with an exception mentioned below, extends to about half a mile (2640 feet) below the level of the sea. This is not more than the sixteen-thousandth part of the earth's diameter.

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* The well of Grenelle in Paris delivers daily, at a height of 86 feet above the surface, and at a temperature of 82°, 744,490 gallons of water.

576. This subject was considered to be of sufficient importance to be brought before the Parliamentary Committee appointed to inquire into the probable exhaustion of our coal-mines in 1871. It was alleged that when a depth of 3420 feet was reached, the temperature would be 98° (blood heat), and that this would put a stop to the further working of coal. At this time the two deepest English pits are reported to have been at Pendleton (2214 feet) and Rosebridge, near Wigan (2424 feet). In this, the deepest mine in England, the temperature of the coal was found to be 93½°. At Charleroi, in Belgium, there is a mine 2640 feet (half a mile) deep, and at Verviers a shaft is reported to have reached a depth of 3511 feet, or nearly 100 feet below the supposed workable limit. The temperature of the strata at this great depth has not been stated, but nothing has occurred to prevent the working of the mine.

577. *Deep-sea Temperatures.*—It might be supposed that from the great depths at which the sea has been fathomed, stronger evidence would be obtained than in the exploration of mines; but from the fact that water has its greatest density at about 40°, and that heat is rapidly distributed by convection or circulation through the vast mass of the ocean, this source of evidence fails.

The most valuable observations on this subject have been either made or collected from authentic sources by Dr. Carpenter. Thermometers which are not protected, are subjected to enormous pressure, *i.e.*, one ton per square inch for every 800 fathoms, or 4800 feet in depth.[*] Then there was an uncertainty in determining temperature at certain depths, as this might change during the time required to raise the instrument to the surface. Messrs. Negretti and Zambra have overcome this difficulty by constructing a deep-sea thermometer, which will allow the temperature to be accurately taken for any known depth.[†]

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[*] A column of sea water one inch in section and 800 fathoms high, weighs just a ton.

[†] The principle upon which this instrument is constructed is as simple as it is ingenious. The thermometer, well protected in the bulb, has a

The pressure of sea-water, however, has hitherto formed a limit to the use of the thermometer. At a short distance north of St. Thomas's, in the West Indies, an extraordinary depression of the bottom of the Atlantic was noticed. The depth was 3800 fathoms (about 4½ miles). The two protected thermometers which had previously withstood the pressure of nearly 4 tons on the square inch were both crushed by the pressure of 4¾ tons to which they were here subjected, and thus the temperature of this deep stratum could not be determined. As far down as the thermometer could be used it was 34½°.*

The subjoined engraving (fig. 161) represents a section of the Mid-Atlantic Ocean, from 38° N. to 38° S. :—

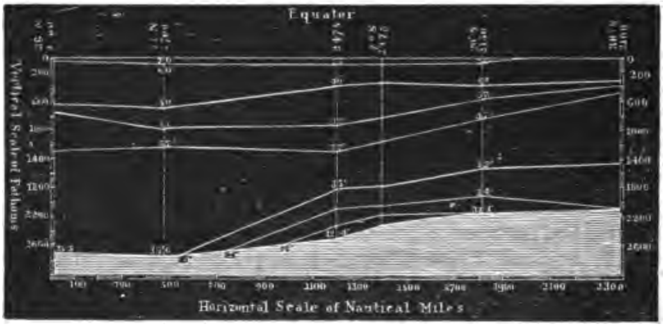

Fig. 161.

This sectional chart is reduced from a larger engraving con-

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syphon-like form, with parallel legs. The thermometrical scale is pivoted on a centre, and it is inclosed within four strong bars. As it descends, the mercury acquires the temperature of the medium through which it is passing. So soon as the descent ceases, and a reverse motion is given to the line so as to raise the thermometer, the instrument, by an ingenious mechanical arrangement, turns over on its centre, and makes a half revolution. The column of mercury then falls into the dilated syphon head at the top, and thence into the right hand tube, where it remains, indicating on a graduated scale, the exact temperature of the sea at the spot at which it was turned over. As the mercury breaks off at one particular point, no more can thus be transferred from one side to the other than that portion which indicates the exact temperature.

* A still deeper sounding was made in the *Challenger* expedition, near the north coast of New Guinea. A strong hempen line was employed, and

structed by Dr. Carpenter. It shows the lines of equal oceanic temperature (isothermal) from the surface to a depth of 2600 fathoms, or 15,600 feet below the level of the Atlantic Ocean.

The temperature observed at this great depth was 35·6°. The thermometer rose as it was drawn to the surface—at 1800 fathoms it was 36°; at 700 fathoms, 40°; at 300 fathoms, 60°; and at the surface, 71°. This was in latitude 38° N. At the Equator the bottom was sounded at 2500 fathoms, and the temperature of the water was 32·4°, the water at the surface being 78°. In latitude 38° S., at 2150 fathoms, the temperature was 33·5°, that of the surface being 54°. This curious chart shows that there are isothermal lines in the depths of the sea as on the surface of the globe, and that similar temperatures are found at different depths, varying with the latitude north and south.*

578. In these results we find no evidence whatever of terrestrial

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this was run out to the extent of 4500 fathoms, or more than *five miles*, the greatest depth to which the ocean has been sounded with any accuracy. Three thermometers out of four were crushed in this experiment by the enormous pressure.

* It is a remarkable fact that the low temperature and great pressure which exist at the bottom of the Atlantic, are not inconsistent with the existence of invertebrate animals. Dr. Carpenter has very properly pointed out that an undue importance has been attached to the supposed effect of pressure on animal life. As he justly observes, the pressure is equal on all sides, and the pores of these animals are filled with water, not air, so that the pressure is neutralized.

Professor Thompson, one of the seventeen members of the *Challenger* Expedition, found that life extended to very great depths in the Atlantic Ocean. It was represented by all the marine invertebrate groups. He procured from a depth of 14,490 feet a dentalium, one or two crustaceans, several annelids, and a new crinoid with a stem four inches long, several starfishes, two hydroid zoophytes, and many foraminifera. The fauna at this depth, owing to the cold, has a dwarfed and Arctic character, no doubt from the influence of the great Arctic current. At from 4800 to 5400 feet below the surface, the temperature being about 40°, the fauna was specially characterized by the great abundance of vitreous sponges.

It is highlv probable, as Dr. Carpenter has suggested, that the presence of life in the deep Atlantic, is mainly owing to the thermal circulation of the waters. It is this which ensures that degree of oxygenation which is really necessary to the maintenance of animal life. By variations of temperature and by increased specific gravity from evaporation, an oceanic heat. The greatest depth at which accurate observations were made may be taken at three miles, six times as far below the sea level as any mine below the surface of the earth. But even this great depth would represent a proportion of only the two thousand six hundredth part of the earth's diameter.

There is reason to believe that the temperature in the depths of the Atlantic, is kept low by the Polar current, for in the Mediterranean, an inland sea, this low temperature is not found.[*] During the winter months the western basin of this sea averages about 54° at the surface, and this temperature is maintained with extraordinary uniformity to the bottom, at 1500 or 1600 fathoms (nearly 10,000 feet), while in the Atlantic, at an equal depth, the temperature was about 35°. In the summer months it is only the surface layer that is affected by solar radiation, the temperature from 50 fathoms downwards remaining constant at 54° throughout the year.

From the observations made by Dr. Carpenter it would appear that the line of 39° (maximum density of water) was generally reached at 1000 fathoms, and that it is an error to suppose that by reason of increase of density, this temperature is always found in the lowest stratum of sea-water.

Although, therefore, owing to the peculiar laws which govern the

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circulation is established which brings every drop of water in turn to the surface. Carbonic acid is thereby removed and is replaced by oxygen.[*]

[*] The Mediterranean is strongly contrasted with the Atlantic in this respect. The bottom temperature ranges from 54° to 56°, showing the entire absence of a Polar current, hence there is no thermal circulation and no life is found below 250 fathoms. It is a great inland basin from 1600 to 2000 fathoms deep (12,000 feet), and the submarine ridge at the Straits of Gibraltar, which is only 200 fathoms or 1200 feet deep, cuts this sea completely off from the great Polar stream passing over the bottom of the Atlantic. For further information on these remarkable thermal conditions of the ocean, the reader may refer to Dr. Carpenter's essay above quoted.

Vertebrate animals could not exist at the great depths at which the invertebrate are found. Captain Scoresby noticed in one of his expeditions that a sperm whale ran out 700 fathoms, or 4200 feet of line. It plunged vertically into the sea, but it is most probable that it did not descend below one fourth of this depth. This would represent an increased pressure of nearly 500 pounds on every square inch of its body.

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[*] 'On the Conditions which determine the Presence or Absence of Life on the Deep Sea Bottom,' by Dr. W. B. Carpenter, pp. 20, 25.

distribution of heat in liquids, the waters of the ocean do not indicate, like the solid strata of the earth, any increase of temperature in proportion to depth, there can be no doubt that, at no great distance below the bottom of the deepest sea, subterranean heat exists. The numerous volcanoes which rise out of the bed of the sea, either active or extinct, in all parts of the globe, from Hecla and Jan Mayen in the north, to Mounts Erebus and Terror in the south, furnish sufficient evidence of the correctness of this inference.

579. The question here arises, What is the source of the heat thus proved to exist in the interior of our planet? No mode of motion, nor any conceivable cause of motion, has been suggested to account for it. The hypothesis of falling meteorites fails—of friction, or percussion, or of chemical combustion there is no evidence, and we can only fall back on the supposition that it is due to the retention of a portion of the primordial heat to which the earth has been subjected, as shown by the abundance and diffusion of igneous rocks over its surface.

> " *The change of the quantity of heat in bodies is conveniently estimated by the concomitant change of their bulk, any substance so circumstanced as to allow this to be accurately measured, serving as a measurer of heat.*"

580. If we heat a wire it is lengthened; if we heat water in a full vessel, a part runs over; if we heat air in a bladder, the bladder is distended: in a word, if we heat any substance, its volume increases in some proportion to the increase of temperature—and this increase of volume admits of measurement. For the measurements of heat generally, a mercurial thermometer is commonly preferred to others. This depends for its action on the expansion of mercury in a closed vacuum tube. A mercurial thermometer is a small bulb of glass filled with mercury, and having a long narrow stalk or neck, in which the mercury rises when expanded by heat, and falls when heat is withdrawn. The stalk between the points at which the mercury stands when the bulb is placed first in freezing and then in boiling water, is divided into a convenient number of parts called degrees, which division appearing on a scale applied to the stalk, is continued similarly above and below these points. (See Art. *Thermometer.*)

> "*Heat, by entering bodies, expands them through a range which includes as three successive stages, the forms of solid, liquid, and vapour or gas; becoming thus in nature the*

grand antagonist and modifier of the effects of that attraction which holds the atoms of bodies together, and which, if acting alone, would reduce the whole material universe to a solid lifeless mass."

581. The solid, liquid, and gaseous states, are physical conditions of matter depending on the amount of heat which penetrates the substance. By heating a solid we may cause it to pass through the liquid and the vaporous or gaseous conditions, and by withdrawing heat from the vapour or liquid, we may cause it to repass into the state of solid. Thus a body expanded by heat returns to its original condition on cooling.

If an experimenter take a body which is as free from heat as human art can obtain it—a bar of solid mercury, for instance, as it may be produced by a bath of solid carbonic acid in ether—and if he then gradually heat such body, it will acquire an increase of bulk with every increase of temperature. At first there will be simple enlargement or expansion in every direction ; then the mass will, in addition, be softened ; then it will be melted or fused, that is to say, in the case supposed, the solid bar will be reduced to the state of liquid mercury, with the cohesive attraction of the atoms nearly overcome. If the mass be still farther heated, it will continue to gain bulk until, at a certain point, some of the atoms will be suddenly repelled from the mass and from one another to much greater distances, constituting then an elastic fluid called vapour or gas, many hundred times more bulky than the same matter in the solid or liquid state, and capable of forcibly distending an enclosing vessel, just as common air distends a bladder ; susceptible, moreover, of dilating indefinitely farther, by farther additions of heat, or by diminution of the atmospheric or other pressure, against which it had to expand during its formation. A subsequent removal of the heat from the gaseous fluid, will occasion a progress of contraction corresponding to the previous progress of expansion, and the various conditions or forms of the substance above enumerated, will be reproduced in a reverse order, until the mercury is again converted into a solid mass, as at first. What is thus true of mercury, is proved by modern chemical art to be true also of all the ponderable elements of our globe, and of many of the combinations of these elements—as water, for instance, which is familiarly known to us in its three forms of *ice*, *water*, and *steam*.

Compound substances generally are decomposed into their constituent elements by great changes of temperature. Thus Mr. Justice Grove has proved that when a platinum ball, made white hot, is introduced into water, the elements, oxygen and hydrogen, are liberated as gases, and may be collected and re-converted into water by the application of a red heat. In the chemical decomposition of water, hydrogen alone is liberated, the oxygen entering into a new combination. This effect on water shows that, besides altering its physical condition, heat can exert a decomposing and a recomposing power on this compound.

582. In the above paragraph, *mercury* has been taken as an illustration ; but this metal, which in this climate is naturally liquid, requires to be cooled to 72° below the freezing point of water before it will assume the solid state, and it must be heated to the very high temperature of 650° before it is converted into an elastic vapour. Hence the changes produced in mercury by heat could be made evident only under very exceptional circumstances. If we take a substance like camphor, which is already a solid, we may easily demonstrate the physical changes which are produced in it by heat and by the withdrawal of heat. A lump of camphor, placed in a retort and heated to 347°, melts or passes into the liquid state. If the temperature is raised to about 400°, it is rapidly converted into a transparent vapour or gas, which, on coming into the air, is deposited in white flocculent masses like snow upon all cool surfaces. Thus distilled from a short and wide-necked retort into a tall jar placed upright, it furnishes a beautiful illustration of the conversion of a solid into a liquid, this into a vapour, and the solidification of the vapour by mere cooling. Benzole, which is ordinarily seen as a liquid, becomes a solid at 32°, and a vapour at 177°. Ether, which is also a liquid at 60°, is converted into gas or vapour at 96°. Pure alcohol is a liquid below 174°, but an elastic vapour above this temperature. It has never yet been brought to the solid state, and thus it is most useful for measuring low temperatures. At 166° below freezing water, it acquires an oily consistency, and its indications of temperature below this, are uncertain. Sulphurous acid, which at ordinary temperatures is a gas, passes into the liquid state when cooled to 14° ; but in order to maintain this condition, it must be kept in hermetically sealed glass tubes. If one of these be broken at the common temperature of the air, under a jar of mercury, it is instantly converted into a large volume of gas. On the other hand, liquid ether is converted into vapour or gas by passing a small quantity under a jar filled with water at or above 100°, and inverted in a basin of water at the same temperature. A teaspoonful of liquid thus forms a large quantity of vapour of ether, which is highly inflammable, and burns like coal gas. If removed to a basin containing water at 60°, the water rises and fills the vessel by condensing the vaporous ether to the liquid state.

These facts shew that the solid, liquid, and aëriform or gaseous states of bodies depend essentially on the presence or absence of a definite amount of heat.

583. *Gases and Vapours.*—The difference between a gas and a vapour is, that a gas is permanently, what a vapour is temporarily. If we take two bladders provided with stop-cocks, and fill one with ordinary coal gas, while into the other, we pour about half an ounce of liquid ether, shut the stop-cock, and then immerse the bladder in water at 170°, the ether will be converted into vapour and expand the bladder just as if it had been filled with coal-gas. A small quantity of the contents may be burnt out of each bladder by opening the stop-cocks. The flames will appear precisely similar. If now the two bladders are placed in a dish, and cold water poured over them, the one with the coal gas will remain unchanged, while that which held the ether-vapour will collapse from its immediate condensation. In a vapour, as represented by ether, we have the gaseous condition of a liquid, the boiling point of which (96°) is above the ordinary temperature, while, in a gas represented by sulphurous acid, we have the vapour of a liquid, the boiling point of which (14°) is below the ordinary temperature of the atmosphere. As these conditions depend on heat, so they vary with climate. In Siberia, during the winter season, sulphurous acid, unless artificially heated, could exist only as a liquid ; while in Egypt and in Central Africa or India, ether could not exist as a liquid, except under pressure in closely secured bottles artificially cooled.

The question then arises,—Are not the bodies which are called *gases* merely the vapours of liquids *uncondensed?* Faraday's researches have furnished an answer to this question. They have shown that with a few exceptions, gases are really the vapours of highly volatile liquids, the boiling points of which are far below the freezing or solidifying point of mercury. By compressing gases in strong tubes of glass, and at the same time cooling them to a very low degree of cold, he was able to bring a large number into a liquid state, and in some cases even into the state of solids. He found that many of them, like sulphurous acid, were liquefied by mere cooling.

584. For this purpose a bath of solid carbonic acid and ether was employed. It was found that a cold of − 106° F. was produced from these materials under exposure to air, and at this temperature eight gases, among which were chlorine and ammonia, passed at once into the liquid state.*

By employing this bath in the vacuum of an air-pump, a more intense degree of cold, – 166° F. or 198° below the freezing point of water, was produced. There were six gases which still remained unchanged at this low temperature, and among these were the important elements, oxygen, hydrogen, and nitrogen. Even when this degree of cold was conjoined with great pressure, these gases still resisted liquefaction. Since these experiments were performed, a lower degree of cold has been produced by Natterer, in employing in vacuo a bath of liquid nitrous oxide and sulphide of carbon. It was estimated in this case at – 220° F., or 252° below the freezing point of water. When exposed to this degree of cold, the gases above-mentioned did not change their state—they were not liquefied.

A student might at first have difficulty in believing that the beautiful variety of solid, liquid, and gaseous conditions found among natural bodies, could depend upon the quantities of heat in them, because these forms are all seen existing at the same common temperature; but he will soon learn that each substance has its peculiar relation or affinity to heat, and that hence, while, at the medium temperature of the earth, some bodies contain so little as to have a solid form—like the metals and earths; others have enough to be liquids—as mercury, water, and oils; and others have enough to be gases—as oxygen, nitrogen, and hydrogen.

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* The intensity of the cold produced by this bath may be estimated from the following experiment performed by Faraday in the presence of the writer. On a warm summer's day, after a lecture at the Royal Institution, a small quantity of mercury was poured into a groove or trough roughly made by folding brown paper. It thus formed a silvery stream of about one quarter of an inch wide and eight inches long. The surface of the liquid mercury was covered with solid carbonic acid, and a small quantity of ether was then poured over it. The carbonic acid was at once liquefied, and the mercury, by cooling, was converted into a pliable metallic bar. It could be touched only, like the solid carbonic acid, with wooden forceps A cold knife cut through it as a very hot knife would cut through wax or butter. A portion of the silvery bar was thrown into a glass of water. The mercury was instantly liquefied and the water frozen to solid ice. Heat was thus transferred from the water to the mercury. The solid metal became a liquid, and the liquid water became a hard solid by the exchange.

The degrees in a general scale of temperature at which the substances most important to man change their states from solid to liquid, or from liquid into gas, will be noted in a future page.

585. Good conducting solids, in melting, melt as soon in the centre of the solid as on the surface, such as lead and bismuth. Those which are bad conductors, on receiving heat become very soft before they are liquefied, as wax, pitch, glue, and glass; but the greater number become liquid at once, as ice in becoming water; and some pass at once into the state of vapour or gas, without having assumed at all the intermediate state of liquid. These last are *sublimed*, as it is called, and on cooling again may be caught in a powdery state, as seen in that form of sulphur, or of benzoin, termed the *flowers* of these substances. Of this class, also, are arsenic and the substance called iodine, which last, from the state of metallic-looking crystals, becomes at once, on being heated, a dense transparent gas of a rich purple hue, and in cooling re-assumes its solid crystalline form.

Many solids, chiefly of the organic kingdom, such as wood, starch, gum, and ivory, are not melted by a strong heat, but undergo chemical changes; in other words, they are decomposed, and new compounds result.

586. Some metals, almost infusible alone, readily melt when heated with other metals. Thus, on heating together platinum and antimony in a spirit flame, the platinum, which is almost infusible, is readily melted, and forms an alloy with the antimony. There is a combination of three metals, which is remarkable in this respect, that it melts at the temperature of boiling water (212°). It is called fusible metal, and is composed of two parts of bismuth, one of lead, and one of tin. The lowest melting point of these three metals is that of tin, 442°.

The melting points of some substances serve to measure temperature. All the under-mentioned bodies melt at what is called a black heat, *i.e.*, a heat not visible in the dark. These are called their points of fusion:—

	Melts at		Melts at
Zinc	773°	Paraffine	112°
Lead	612°	Phosphorus	108°
Bismuth	500°	Tallow	92°
Tin	442°	Olive oil	36°
Sulphur	232°	Ice	32°
Wax	142°		

There are slight variations in these melting points, in the tables given by different writers. It has been pointed out as a curious fact that no fusible solid can be heated above its true melting point without being liquefied; but some liquids can be cooled below the solidifying point mentioned and still remain liquid. This is the case with water. The melting point of ice is always 32°, but the freezing point of water contained in glass tubes may be carried to 24° below this, and even if the tube be capillary, nearly to zero F.

Saline matter dissolved in water lowers the freezing point. One part of common salt in four parts of water freezes at 4°. The freezing point of sea water, which contains between three and four per cent of salt, is 28°.

There is a remarkable difference among solids in this respect. One is known to exist only in the solid state, namely carbon in the native form of diamond. The most intense heat of the voltaic arc does not cause its liquefaction or volatilization. It is merely converted into black amorphous carbon. Among liquids, alcohol has never been solidified; and among gases, oxygen has never been liquefied or solidified.

587. *Solidification of Gases.*—It has been shown by an illustration of the properties of camphor how a vapour may be solidified (Art. 582). It is the mere result of the withdrawal of heat or of cooling, under peculiar conditions. Ammonia, chlorine, and carbonic acid gases have been converted from liquids into solids. The last-mentioned gas will serve to illustrate the principle. Carbonic acid liquefied in a wrought-iron vessel is allowed to escape in a gaseous state through a perforated brass cap. So great a cold is produced by its sudden expansion, that a quantity of the gas is solidified in a snow-like form in the brass capsule, and it retains its solid state for some time in a cold vessel. The liquefaction of gases has been brought into commercial use. Thus, liquefied ammonia or sulphurous acid, by the intense cooling which each produces in assuming the gaseous state, have been used for converting water into thick slabs of ice in a few minutes.

> "*Heat diffuses itself among neighbouring bodies until all have acquired the same temperature; that is to say, until all will similarly affect a thermometer.*"

588. An iron bolt thrust in among burning coals soon becomes red-hot like them. If it be the heater of a tea-urn, it will, when afterwards placed in its receptacle amidst the water, give part of its lately-acquired heat to the water, until the water boils. Boiling water, again, soon imparts heat to an egg placed in it. A hundred objects enclosed in the same apartment, if tested after a time by a thermometer, will all indicate the same temperature.

589. *Heat and Cold.*—When the hand touches a body of higher temperature than itself, it receives heat according to the law just explained, and it experiences a peculiar sensation called that of warmth · when it touches a body of lower temperature than itself, it gives out heat for a like reason, and experiences another and very distinct sensation called that of coldness. Now warmth and coldness, considered as existing in the bodies themselves, although thus appearing opposites, mark only different degrees of the same object, *temperature*, contrasted by name for convenience-sake, in reference to the ordinary temperature of the persons speaking of them—just as any two nearest mile-stones on a road, although merely marking degrees of the same object, *distance* from a place, might receive from persons living between them the opposite names of east and west, or of north and south. It is to be remarked, moreover, that the sensation of heat is also producible by a substance colder than the hand in its ordinary state, provided it be less cold than some other substance touched immediately before, or than the usual temperature of the place; and the sensation of cold is producible under the opposite circumstances of the hand touching a comparatively warm body, but which is less warm than something touched just before. This explains the fact that the same body may at the same time, and to the same person, appear both hot and cold. Let two basins be filled with equal quantities of water—one at about 40°, and another at 90°—and a hand placed in each. In the former there will be a strong sensation of cold, and in the latter of warmth. The water in the two basins may now be mixed in a larger vessel, and both hands plunged into the mixture. Although the temperature, as indicated by a thermometer, is 65°, the water will feel warm to one hand and cold to the other, but there is the same amount of heat in both. A cellar of which the temperature does not vary, feels warm in winter and cold in summer. For a like reason, a person from India, arriving in England in the spring time, deems the air cool, while the inhabitants of the country may be diminishing their clothing because the heat to them might appear oppressive. Such facts as these show that heat and cold are relative terms depending on pre-existing sensations, and that that which is cold to one person may be warm to another. It is necessary, therefore, to look for more correct indications of temperature than our bodily sensations.

Water as ice feels cold, but a thermometer may be cooled to near the freezing point of mercury (−40° F.). By plunging a thermometer so cooled into ice, the mercury in the tube will rise, showing that it is warmed by the ice, and demonstrating that the ice contains heat.

"*Heat spreads through solid substances by conduction, as it is called, with a progress proper to each substance.*"

590. If one end of an iron rod be held in the fire, a hand grasping the other end soon feels the heat coming through it. The shorter and thinner the rod the more rapidly is this sensation perceived, and if a copper rod is substituted for the iron rod the heat is sensibly felt much sooner. Through a similar rod of glass, the transmission is much slower, and through one of wood or charcoal it is slower still. The hand would suffer pain from holding the iron before it felt any warmth in the wood or charcoal, although the inner end of the wood were blazing and the charcoal were red-hot.

These facts show that different substances conduct heat with different degrees of rapidity, and on this property many interesting phenomena in nature and in the arts depend. Hence it is important to ascertain the rate of transmission, and to classify the substances accordingly. Various methods for this purpose have been adopted. For solids—similar rods of different substances, after being thinly coated with wax, have been placed with their ends in hot oil, and then the comparative distances to which in a given time the wax was melted, furnished one set of indications of the comparative conducting powers. Another method consisted in heating to the same degree equal masses of different substances, with a central cavity in each containing a thermometer. The substances were then plunged into the same bath to cool, until the thermometer fell in all to a given point; the differences of time which elapsed gave the relative rates of cooling.

591. The following is a simple method of showing the relative conductivity of solids. Place bars of copper and iron about nine inches long and a quarter of an inch in thickness on a block of wood, and by the side of them a similar bar cut out of charcoal. The ends of the three bars should be brought in contact, so that they may be at once easily moved into a wide spirit-lamp flame. They should so diverge as to be two or three inches apart at the opposite ends. Place three small fragments of phosphorus at equal distances on each of the bars, the first being placed at about three inches from the flame, and the others at three inches apart. Gently bring the ends of the three bars into the flame, so that they may be equally heated, and place a screen so as to cut off draughts of air. It will be observed that the first phosphorus on the copper will soon melt and take fire. This indicates a temperature of 113°. At an interval after this, the first on the iron. The three portions on the copper will generally be melted and ignited by the time the second on the iron is reached. Charcoal, being a non-conductor, becomes red-hot at the heated end and burns before the first phosphorus on it is melted, provided we guard against the radiation of heat.

A silver and an electro-plated tea-spoon may be distinguished by a difference in conductivity. If a small fragment of phosphorus is laid on the extremity of the handle of each teaspoon, and the bowls of the spoons are then dipped into boiling-hot water, the silver will be indicated by the earlier ignition of the phosphorus.

The handles of silver teapots and kettles are frequently divided, and thin layers of ivory introduced for the purpose of preventing the rapid conduction of heat by this metal, which, in conducting power, takes precedence of all other metals.

These and other experiments have shown, as a general rule, that density favours the passage of heat through a solid. Thus, the best conductors are the metals, and then follow in succession, diamond, glass, stones, earths, woods, &c, as here noted. The numbers standing after the names, mark the approximate conducting powers of metals in relation to silver, taken as a standard and called 100.

Silver	100·0	Iron	11·9
Copper	77·6	Steel	11·6
Gold	53·2	Lead	8·5
Brass	23·6	Platinum	8·4
Zinc	19·0	Palladium	6·3
Tin	14·5	Bismuth	1·8

These results have been obtained by Messrs. Wiedemann and Franz by the use of a thermo-electric pile (to be afterwards explained), applied to the extremities of bars of the different metals of similar size and treated under similar circumstances.

These figures differ greatly from those which had been previously obtained by Despretz and hitherto relied on by physicists.

592. The presence of impurities, such as arsenic or carbon, in metals lowers their conducting power for the electric current, and probably also for heat. This is remarkably the case with copper. Steel containing carbon is a worse conductor than iron. The conducting power of minerals or earthy substances is much less than that of metals—*e.g.*, marble, 2·36; porcelain, 1·22; fire-clay, 1·14.

The following articles used in building have a relative conducting power expressed by the following figures, compared with slate (100):—

Slate	100·00	Bath stone . . .	61·08
Magnesian limestone	76·35	Stock brick . . .	60·14
Portland stone . .	75·10	Lath and plaster . .	25·55
Lunelle marble . .	75·4	Plaster of Paris . .	20·26
Fire brick . . .	61·70	Plaster and sand .	18·70

These results were obtained by Mr. Hutchinson in experiments on the building stones employed for the Houses of Parliament. The warmest substances, or those which resist most the passage of heat, are the lowest in the scale.

Marble is a better conductor than plaster or cement. A marble column feels much colder than one made of artificial scagliola.

Sulphur is a very bad conductor of heat. If a roll of sulphur is held over a candle it cracks immediately. Even the warmth of the hand will cause it to crack. The heat is not conducted off, but concentrated at the part heated, and the solid gives way, owing to sudden expansion.

593. Solids are usually divided into conductors and non-conductors; but all bodies conduct heat more or less, hence the latter term is incorrect. As the above table shews, the various substances differ only in degree. Of all earthy substances, asbestos is probably the one which most retards the passage of heat, or possesses the least conductivity. The writer has tested the properties of this substance by holding for a short time a red-hot poker in his hand covered by a thick asbestos glove. Its fibrous and porous structure prevents the ready transmission of heat (Art. 58, p. 23).

A mass of red-hot coke soon cools and becomes black on the exterior, although a red heat is still maintained in the interior. An equal mass of red-hot iron remains visibly red-hot for a much longer time, and it is long before it appears black on the exterior. The coke is a bad conductor and retains the heat, while the iron is a good conductor and conveys heat rapidly through its substance

The lava of volcanoes is a very bad conductor of heat. It rapidly cools and becomes black on the rugged surface, but at two or three feet below it retains a red heat for weeks, months, and even years, according to the thickness of the current. The writer observed, when ascending Vesuvius in 1829, that a stratum of lava which had been thrown out in an eruption a year before still retained a great degree of heat below. When on the brink of the crater, he also noticed that the fused lava thrown out in huge flakes from the inner cone to the height of at least 600 feet, appeared quite black as it reached the atmosphere, but on falling on the floor of the crater the lava broke into fragments, and showed a red heat in the interior. It was then so soft that coins could be thrust into it.

594. Porous wood-charcoal is a bad conductor, but the dense form of native carbon known as diamond, readily conducts heat. By the application of a diamond to his lip, a jeweller is able to distinguish the diamond from a paste imitation by the sense of coolness which it imparts, owing to its higher conducting power.

It would be a mistake to suppose that the denser the metal, the more readily it conducts heat. Thus platinum is much denser than silver, but it has only one-twelfth of the conducting power. Copper is superior to gold in conductivity.

It requires the closest contact of atoms to manifest this property. If a bar of copper is cut through, it ceases to conduct, or at any rate heat is transmitted only slowly, although the cut ends are in the closest contact. Finely divided metals, as iron filings or spongy platinum, have but little conducting power compared with that of the solid metal. Finely divided or porous mineral substances, for a similar reason, oppose the ready transmission of heat. Red-hot cannon balls may be safely carried on sand.

595. Count Rumford adopted the following method in order to ascertain the relative degrees in which furs, feathers, and other organic materials used for clothing, conduct heat, or, which is the same thing, resist its passage. He covered the ball and stem of a thermometer with a certain thickness of the substance to be tried, by placing it within a larger bulb of glass, and then filling the surrounding interval between the two with the substance; and after heating this apparatus to a given degree by dipping it in liquid of the desired temperature, he surrounded it by ice, and marked the comparative times required to cool the thermometer a certain number of degrees. The figures following the names of some of the substances in the subjoined list, mark the number of seconds required respectively for cooling down the thermometer through sixty degrees of Fahrenheit :—

Sewing-silk	917	Wool	1118
Wood-ashes	927	Raw silk	1284
Charcoal	937	Beavers' fur	1296
Fine lint	1032	Eider down	1305
Cotton	1046	Hares' fur	1315
Lamp-black	1117		

This table may be read thus : the greater the number of seconds required to cool down to the standard, the worse the conducting power of the substance, and the greater the amount of heat retained.

Owing to its lightness and the large amount of air which it locks up, the down of the eider-duck is one of the worst conductors known, and is, therefore, best adapted for retaining or preventing the access of heat.

596. In reference to *air*, if its particles are not allowed to move about among themselves, so as to *carry* heat from one part to another, by what has been called *convection*, it *conducts* (in the manner of solids) so slowly, that Count Rumford doubted whether it conducted at all. It is probably the worst conductor known, that is, it is the substance which, when at rest, impedes the passage of heat most. To this fact seems to be owing, in a considerable degree, the remarkable non-conducting quality of porous or spongy substances, as fur, feathers, loose filamentous matter, powders, &c., which have much air in their structure, often adherent with a force which immersion in water, or even their being placed in the vacuum of an air-pump, can scarcely overcome.

Double windows are very effectual in retaining heat by reason of the non-conducting stratum of air between them.

In heating an apartment with warm air, this should be always let in from the lowest part. If it enters above, it simply floats on the stratum of cold air below, without warming the room generally.

597. While contemplating the facts set forth in the above table, one cannot but reflect how admirably adapted to their purposes the substances are which nature furnishes as clothing for the inferior animals, and which man afterwards accommodates with such curious art to his peculiar wants. These animals required to be protected against the chills of night and the keen blasts of winter ; and some of them which dwell among enduring ice could not have lived at all but for a garment which should shut up within them nearly all the heat which their vital functions produced. Those textures, or coverings, which are known under the name of fur and feather, perfectly protect the wearers. These textures grow from the bodies of the animals in quantity exactly suited to the climate and season, and are reproduced when, by use or wear, they become too thin. In warm climates the hairy coat of quadrupeds is comparatively thin : as of the elephant, the monkey, the tropical sheep, &c. It is seen to thicken as the temperature is lower, furnishing the abundant fleeces of the temperate zones ; and towards the poles it is externally shaggy and coarse, and internally shorter and finer, as in the Arctic bear, &c. In amphibious animals, which have to resist the cold of water as well as of air, the fur acquires a peculiar character, as in the otter and beaver. Birds, from having very warm blood, require for the preservation of heat a warm covering, and in order that they may pass easily through the air this covering should be at the same time light, strong, and smooth. These objects are secured by the marvellous structure and arrangement of feathers. Feathers, like fur, appear in kind and quantity suited to particular climates and seasons. The birds of cold regions have plumage almost as bulky as their bodies ; and those of them which live much in the water have, additionally, both a defence of oil on the surface of the feathers, and the interstices of the ordinary plumage filled up by the still more delicate structure called down, particularly on the breast, which in swimming first meets and divides the cold wave. There are animals with warm blood which yet live immersed in water, as the whale, seal, walrus, &c. ; and neither hair nor feathers, however oiled, would have been a fit covering for them ; but they are furnished with an equal protection in the vast mass of fat or blubber which surrounds their bodies, giving them buoyancy and completely retaining internal heat.

In reference to the vegetable kingdom, it may be observed that the bark of trees is also a structure slowly permeable to heat, and therefore it serves to retain the temperature which is necessary to vegetable life.

598. While we admire what is thus provided for preserving heat in animals and vegetables, we must not omit to notice the important protection of snow and ice, as winter clothing for the fields and gardens, for the lakes and rivers. Ice is at all times lighter than water, and floats on the surface. Its specific gravity has been found to be ·918 at 32°, and ·920 at 0°. It is, therefore, rather more than $\frac{1}{12}$th lighter than its bulk of water.* Ice is a very slow conductor of heat, and defends the water underneath from the cold air above, preserving it liquid and as a fit dwelling for the finny tribes. By this arrangement the extreme of cold is not only thus prevented below, but a moderate temperature sufficient for the life of fishes is preserved throughout the water. In the formation of ice, therefore, nature, by a remarkable exception to the general law of crystallization, has secured a winter garb or protection for the inhabited lakes and rivers as effectual as for terrestrial animals by the periodical thickening of their wool or fur. Snow, which may be called the pure white fleece of the earth, is a structure which resists the passage of heat nearly as much as feathers. It consists of fine crystallized spicula closely entangled and locking up, as they fall to the earth, a large quantity of air as well as many impurities contained in the atmosphere. A common form of snow-crystal is given in the annexed engraving (fig. 162). These crystals are generally in the shape of hexahedral plates, the spicula crossing each other at an angle of 60°. It has been found by direct experiment that sixty cubic inches of compressed snow will yield only eight cubic inches of water in the liquid state. Snow, of course, has to defend substances only from degrees of cold below 32°, or the freezing point; but it does this most effectually by preserving the roots, and seeds, and tender plants during the severity of winter. Under deep snow, while the thermometer in the air may be far below zero, the temperature of the ground rarely remains below the freezing point; and this temperature, to persons who have to bear sharper cold in the outer air, is mild and even agreeable. It is much higher than what often prevails for long periods in the atmosphere of the north of continental Europe. The Laplander, who, during his winter, lives chiefly under ground, is glad to have additionally overhead a thick covering of snow. Among the hills of the north and west, even of Britain, during the storms of winter, a covering or shelter formed of snow

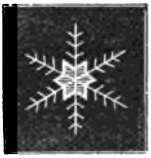

Fig 162.

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* This will serve to convey a notion of the enormous masses of the icebergs found floating in the sea. One measured by Dr. Hayes in Melville Bay, was 315 feet in height and three-quarters of a mile in length. There was twelve times as much ice below as above the level of the sea. Its estimated weight was two thousand millions of tons. The influence of these vast masses of solid water at 32°, in lowering the temperature of the air and sea for a great distance around them may be readily understood.

frequently preserves the lives of travellers, and even of whole flocks of sheep, where the keen north wind, finding them unprotected, would soon extinguish life.

Conducting Power of the Earth. Stratum of fixed Temperature.

599. It is because the strata of the earth conduct heat slowly, that the intense frosts of winter and the direct sunbeams of summer penetrate but a short way into it. The temperature of the ground, a few feet below its surface, is nearly the same all the year round, for the extent to which the solar heat penetrates is exceedingly small. This is easily determined by burying thermometers in the earth, or fixing them at different depths in mines and other excavations. The experiments hitherto made, lead to the following interesting results. Diurnal variations of temperature are not perceived beyond two or three feet. Variations depending on the months or seasons extend somewhat lower; and annual variations are entirely lost at a depth of from 60 to 100 feet, varying in different localities. Hence it follows that the maximum depth at which the changes in the thermometer are perceptible, amounts to only the 400,000th part of the earth's diameter. Upon the alternate heating and cooling of this film, which does not exceed the 9,000,000th of an inch in a globe of three feet in diameter, depend all the vicissitudes of temperature in climates, seasons, and cycles of years.

The depth at which a thermometer undergoes no change has been accurately determined for these latitudes by experiments made at Paris. In July, 1783, a very delicate thermometer was placed by Lavoisier, an eminent philosopher who fell a victim to the great French Revolution, in an excavation beneath the Observatory of Paris, at a depth of 90 feet below the surface of the ground. This thermometer was so sensitive to changes of temperature as to allow of the measurement of what would be equivalent to the 100th of a degree on Fahrenheit's scale. From observations made by Cassini, Bouvard and others, extending over a period of fifty years, this thermometer remained stationary at a point corresponding to 53° F., which is about a degree and a half above the mean temperature of Paris. On one occasion only in seventeen years, it was observed to rise a quarter of a degree. This movement was attributed to the effect of currents of air from some excavations made in quarries adjoining the Observatory. Hence in Paris the position of the ***invariable stratum*** of temperature is fixed at from 80 to 100 feet below the surface. In no other place in the world has so accurate a series of observations been made; but from a few data, and from theoretical considerations, the stratum has been considered by Humboldt to exist throughout Europe, between the parallels of 48° and 52°, at from 55 to 60 feet below the surface. Professor Thomson considers its depth in England to be from 30 to 60 feet, and the experiments performed by Mr. Fox in the mines of Cornwall render it probable that in that county it is situated at from 60 to 75 feet.*

M. Baer found that at Yakutsk, in Eastern Siberia, the frozen ground was thawed during the short summer to the depth of only 3 feet. Below that, at all periods of the year, there is a band of ice or frozen soil which has been perforated to the depth of 382 feet, but without entirely traversing it. The solar influence, therefore, in this desolate region, scarcely extends in the course of seasons beyond 3 feet from the surface. This may explain the fact mentioned by Erman, that the body of Prince Menschikof, one of the favourites of Peter I., which had been buried in this frozen soil at Beresov, was exhumed in 1821, and was found to have undergone but little change, although ninety-two years had elapsed since the burial!

As a general rule, it is considered that the mean temperature of the locality corresponds to the temperature of the invariable stratum. A thermometer carried below it continues to rise in proportion to the depth, although there is no regular rate of increase.

600. As further illustrations of the imperfectly conducting power of the earth may be mentioned the following facts:—Water in pipes which are laid two or three feet under ground, as in the streets of cities, does not freeze, although it may be frozen in all the smaller branches exposed above. Hence, again, springs of water do not freeze, and therefore often become remarkable features in a snow-covered country; the living water, after issuing from the bowels of the earth, is seen running a considerable way through fringes of green, before the frost can arrest it. A spring at the bottom of a frozen pond or lake may cause the ice to be so thin over it, that a skater arriving there may break through. The spring water, which appears warm in winter, is deemed cold in summer, although really of the same temperature, because in summer it is compared with the warmer atmosphere and objects around it, and in winter with the colder. In proportion as buildings are vast and massive, they acquire more of the quality of uniform temperature here spoken of. Many of the Gothic halls and cathedrals are called cool in summer and warm in winter, as are also old-fashioned houses or castles with thick walls, embayed windows, and deep cellars. Natural caves in the mountains or by the sea-shores furnish other examples of a similar kind.

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* In excavating great masses of earth, even above the sea-level, a high temperature is commonly found. Thus in the tunnel of the Mont Cenis, about halfway through, and nearly four miles from the Italian side, the temperature of the air was found to be 86·2°. At this point the height of rock above was 5280 feet, or one mile. This portion of the tunnel is 4250 feet above the sea level, and the total height of the mountain is 9530 feet.

601. When in the arts it is desired to prevent the passage of heat out of or into any body or situation, a covering of a slow-conducting substance is employed. Thus, to prevent waste of heat from a smelting or other furnace, it is lined with fire-bricks, and thickly covered with a kindred material. A furnace so guarded may be touched on the outside by the hand with impunity, even while having within it melted iron. To prevent, during the winter, the freezing of water in pipes, by which occurrence the pipes would be burst, it is common to cover them with straw-bands or coarse flannel, or to enclose each in a larger outer pipe, the interval between the two being filled up with dry charcoal, sawdust, spent tan, or chaff. If a pipe, on the contrary, be for the conveyance of steam or other warm fluid, the heat in it is retained, and therefore saved by the very same means. Ice-houses are generally made with double walls, between which dry straw is placed, or sawdust, or air, to prevent the passage of heat. Pails for carrying ice in summer, or intended to serve as wine-coolers, are guarded on the same principle. A flannel covering keeps a man warm in winter—it is also powerful to keep ice from melting in summer.

In the cylinder of a steam-engine, and in the body of a locomotive the heat is preserved by surrounding them with wooden casings, with a space between to receive powdered charcoal, sawdust, cotton, or some light material which operates as a non-conducting medium, and prevents the passage of heat outwards. The "cosies" made for covering teapots consist of cotton bags stuffed with cotton-wool. The heat is thus retained for a considerable time.

Fire-proof safes and refrigerators used for preserving ice are constructed on a similar principle. Each safe is provided with a double casing filled with some non-conducting material, and in the refrigerator there is a wide space for air. Heat does not readily penetrate from the outside, owing to this non-conducting space. Documents placed in a fire-proof safe may be thus preserved from entire destruction, and the ice in a refrigerator may be kept for a long time without melting.

Urns for hot water, tea-pots, coffee-pots, &c., are sometimes made with wooden or ivory handles, because, if metal alone were used, it would conduct the heat so readily that the hand could not bear to touch them.

602. It is because brittle substances like glass and earthenware do not allow a ready passage to heat, that vessels made of such materials are so frequently broken by sudden changes of temperature. On pouring boiling water into such a vessel, the internal part is so much heated and expanded before the external part has felt the influence by conduction, that the inner portion is riven or cracked by its connection with it. A red-hot rod of iron drawn along a pane of glass will divide it almost like a diamond knife. Even cast iron, as in the backs of grates, iron pots, &c., although conducting more readily than glass, is often, owing to its brittleness, cracked by unequal heating or cooling, as from pouring cold water on it when hot. Pouring cold water into a heated glass, or boiling water into a cold glass, will produce a similar effect. Hence glass vessels intended to be exposed to sudden changes of temperature, as retorts for distillation, flasks for boiling liquids, &c., are made very thin, so that the heat may pervade the whole substance almost instantly and therefore safely.

Action of heat on glass.—Annealing.—Tempering.

603. Any glass, if cooled suddenly when first made, remains very brittle, for the reason now explained. What is called the *Bologna phial* is a very thick small tube, cooled rapidly, which is broken into fragments when a grain of sand or a piece of flint is allowed to fall into it. The process of annealing, to render glass-ware more tough and durable, is merely the allowing it to cool very slowly in an oven, so that the whole may lose its heat nearly at the same rate.

Toughened glass.—A new process has been recently discovered by which the brittleness of glass is in a great measure removed. This is called *toughening*. The glass after manufacture is heated up to a certain degree, and plunged while so heated into an oil-bath at a temperature short of the boiling point (650°). It is dipped into the heated oil, and instantly withdrawn. The glass preserves its transparency, but undergoes a remarkable molecular change. Its hardness as well as its cohesion is increased, and it appears to be brought in some respects to the condition of the glass in a Rupert's drop, or of the Bologna phial above mentioned. It is not affected by sudden changes of temperature like ordinary glass. It may be thrown with some violence on a deal floor or against a wall without being broken; and from the experiments of the inventor, M. de la Bastie, it will bear from 80 to 100 times the strain of ordinary glass without breaking. A brass weight, allowed to fall on a square of ordinary glass from a height of two feet, broke it into several fragments. With a thinner piece of toughened glass, no impression was made in allowing the same weight to fall upon it from a height ranging from two to ten feet. The brass weight simply rebounded from it. When the weight fell from a height of six feet, the glass broke, but, unlike ordinary glass, the whole mass fell into a fine powder. Like Rupert's drop at the larger end, this glass possesses enormous cohesive force and may be struck with a mallet without breaking; but if the equilibrium of the mass is once disturbed at any one point, a general disintegration takes place throughout the whole mass. Water may be boiled in a vessel of toughened glass over a naked fire, and the vessel suddenly cooled without fracture. It cannot, like other glass, be cut with a diamond, which shows the existence of a distinct molecular structure, a fact otherwise proved by its action on polarized light (to be afterwards explained). It admits of engraving in the ordinary way, or by the action of hydrofluoric acid. As yet it has scarcely come into general use.

The effect of heat in the tempering of metals is a well-known process, having some relation to that now described. (See Art. 53, p. 21.) It depends on molecular changes produced by heating and suddenly cooling the metal. Steel thus suddenly cooled by plunging it into a cold liquid becomes intensely hard. On the other hand, bronzé, an alloy of copper and tin, treated in the same manner, becomes very soft.

604. It is the difference of conducting power which is the cause of a very common error made by persons in estimating the temperature of bodies by the touch.

In a room without a fire all the articles of furniture soon acquire the same temperature; but if in winter a person move a bare foot from the carpet to the wooden floor, from this to the hearthstone, or from the stone to the steel fender, his sensation deems each of these objects in succession colder than the preceding; the truth being, that although all have the same temperature, but inferior to that of the living body, the best conductor, when in contact with the body, is deemed the coldest, simply because it conducts or carries off heat the fastest. Were a similar experiment made in a hot-house, or in India, while the temperature of every object around was at 98°, or that of the living body, then not the slightest difference would be felt in any of the substances. Or, lastly, were the experiment made in a room where, by any means, the general temperature were raised considerably above blood-heat, then the carpet would be deemed the coolest instead of the warmest, and the other things would appear hotter in the same order in which they appeared colder in the winter room. Were a bunch of wool and a bar of iron exposed to the severest cold of Siberia, or that of an artificial frigorific mixture, a man might touch the first with impunity (it would merely be felt as rather cold); but if he grasped the second, his hand would be instantly frozen. Were the two substances, on the contrary, transferred to an oven, and heated as far as the wool would bear, he might again touch the wool with impunity (it would then be felt as rather hot), but the iron would burn his flesh. The writer once entered a place where there was no fire, but where the temperature from hot air admitted, was sufficiently high to boil the fish, &c., of which, in another room, he afterwards partook at dinner. He breathed the hot air without uneasiness. He could bear to touch woollen cloth in the hot room, but no substance more solid.

605. Those who indulge in Turkish baths, in which the air is sometimes heated to 170° or 180°, can sit or tread only on wood or some badly conducting material. The contact of any metal with the skin produces a painful sense of burning. For this reason, the bather is wrapped in a blanket, and is provided with a pair of wooden slippers, in order to protect his feet against the great heat of the marble floor.

Liquid mercury, by reason of its great conducting power, feels cool to the hand plunged into it; but a bar of the metal in a solid state cannot be touched without instantly destroying the life of the part. In passing to the liquid state by contact with the skin, the metal, which has a temperature of 40° below zero F., absorbs and removes all the heat of the part with which it is in contact. The part dies, and finally separates by mortification.

The physical condition of a substance at a very low temperature will greatly affect its conducting power. Solid carbonic acid, which is a white snowy-like solid, at a temperature considerably below that of frozen mercury (−106°), may be held in the palm of the hand

and even pressed, without any particular sense of coldness or pain. There is merely a slight pricking sensation. It is rapidly evolving a gaseous body, namely carbonic acid, which, as a gas, is a non-conductor, and thus direct contact with the skin is prevented. If a small quantity of ether is poured over it, the solid acid is instantly dissolved, producing a cold of 166° below zero, and if this comes in contact with the skin, its vitality would be instantly destroyed.

The non-conducting power of glass, and the effect of suddenly cooling one side, is singularly illustrated by the action of the liquefied gas. If some solid carbonic acid is placed on the surface of thick plate glass, and a small quantity of ether poured upon it, the glass instantly flies to pieces, owing to the sudden and intense cold produced.

606. It is a vulgar error, then, to suppose that there is a positive warmth in the materials of clothing. The thick cloak which guards a Spaniard against the cold of winter, is also in summer used by him as a protection against the direct rays of the sun; and while in England, flannel is our warmest article of winter dress, yet we cannot more effectually preserve ice in summer than by wrapping the vessel containing it in many folds of the softest flannel. That which prevents the heat from penetrating, also prevents it from escaping.

In every case where a substance of lower temperature than the living body touches it, a thin surface of the substance immediately in contact shares the heat of the bodily part touched—the hand generally; and while, in a good conductor, the heat so received quickly passes inwards, or away from the surface, leaving this in a state to absorb more, in the tardy conductor the heat first received tarries at the surface, which consequently soon acquires nearly the same temperature as the hand, and, therefore, however cold the interior of the substance may be, it does not cause a strong sensation of cold. The hand on a good conductor warms it deeply; on a slow conductor, only superficially. The following cases further illustrate the same principle :—Wrap a layer of paper tightly round a brass or iron cylinder about an inch in diameter, and round a wooden cylinder of the same dimensions, and hold them over the flame of a spirit or gas lamp; the paper on the wood will begin to burn immediately, while that on the metal will resist the heat for some time ;—or, if pieces of paper be laid separately on a wooden plank and on a plate of steel, and a burning coal be then placed on each, the paper on the wood will begin to burn long before that on the plate. The explanation is, that the paper in contact with the good conductor, imparts to it so rapidly the heat received from the coal, that it remains at too low a temperature to inflame, and will even cool to blackness the part of the coal which is in contact with it; while on the tardy conductor, the paper becomes almost immediately as hot as the coal, and burns. It is because water open to the atmosphere cannot be heated beyond 212°, that it may be made to boil in an egg-shell or a vessel made of paper, held over a lamp, without the containing substance being destroyed; but as soon as the water is dried up, the paper will burn and the shell will be calcined. The heat is here transmitted through the substance to the water, and is carried off in vapour.

As a remarkable instance of the useful application of these principles regarding the conduction of heat by metals, may be mentioned the *Miner's Safety Lamp*, invented by Sir Humphry Davy.

607. Davy found that fine iron wire woven into a metallic gauze, having from 700 to 800 meshes in the square inch, operated as a powerfully conducting surface, and rapidly cooled flames below their igniting or combustible points. When a layer of gauze of this kind, *a b*, is held over a jet of coal gas, *c* (fig. 163), the gas and air will traverse the meshes of the gauze, and be inflamed above it, at *d*, continuing to burn without igniting the jet of gas below the gauze, the heat of the flame being so reduced by the conducting power of the fine metallic wires as to cool it below the temperature required for ignition. Here, then, in spite of the presence of an inflammable, and even explosive, mixture of coal-gas and air below the gauze, and between it and the jet, there is no communication of the flame, which cannot pass down. If, however, by continued combustion, the wire gauze becomes red-hot, the mixture of gas and air below it will be ignited, the heat of the flame not being cooled by conduction under these circumstances. So, if the miner continues to work with the wire gauze of his lamp red-hot, the flame may tra-

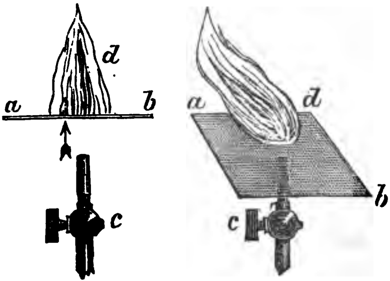

Fig. 163.

verse the gauze, and lead to an explosion. A heat of full redness is, however, required for this purpose.

608. The following experiments will serve as further illustrations of the power of conduction in iron wire gauze. Place a piece of camphor in the middle of the gauze, and hold it over the flame of a spirit-lamp. The camphor will take fire, and burn below, but not above, although there is a large quantity of highly inflammable camphor vapour escaping from it. Tow soaked with alcohol or ether may be substituted for the camphor with similar results. Into a small cylinder of wire gauze, closed with gauze at the bottom, but open at the top, throw a mass of tow soaked in alcohol and inflamed. The cylinder may now be placed in a saucer containing alcohol, when the whole of the spirit will be gradually drawn through the meshes and consumed within the cylinder, but there will be no inflammation of that which is on the outside. Let the same cylinder be fitted closely to a wire-stand supporting a wax taper, so that when the taper is kindled it may be completely enclosed by the gauze cylinder placed over it, and can receive air only through the meshes. If a jar of hydrogen, or coal gas, or a mixture of either with air, be brought over the cylinder inverted, and very gradually lowered, the inflammable gas will traverse the gauze and burn with flame, but without explosion, in the interior of the cage, but there will be no kindling of the explosive mixture on the outside. In this manner the whole of the inflammable gas may be consumed without being inflamed in the jar, whereas, if any such mixtures were brought over the lighted taper not covered by the gauze cylinder, there would be instantaneous inflammation and explosion.*

609. *The Miner's Safety Lamp.*—The safety lamp is an oil-lamp in which the flame is surrounded with a cylindrical cage of fine wire gauze (see fig. 164, which represents it entire, and fig. 165, in section). The wire gauze is double at the top to guard it against the heat of the flame. There is a framework of strong iron wire to support the cage, and by an ingenious arrangement, a brass tube passes up through the oil, in which a wire bent at the top works stiffly, so that the wick may be trimmed without rendering it necessary to remove the cage. The lamp when properly used, not only protects the miner from the danger of explosion, but serves as an indicator of the safety or danger of the atmosphere in which he is working. If the air is pure, the lamp burns with a bright clear flame, the light somewhat reduced by its having to traverse the gauze. If a small quantity of fire-damp is present, the flame becomes elongated and smoky. In larger and dangerous quantities the flame is extinguished, and the mixed gas and air burn inside the gauze cylinder without igniting the mixture outside. Taken into pure air, this inner combustion ceases, and the wick is re-kindled. If allowed to remain with the mixed gases burning inside, the gauze may become red hot, and then the flame will traverse and cause an explosion. There are other sources of danger under these circumstances. A small particle of coal-dust falling upon the heated wire of the cage may be kindled into flame on the outside, and the fire-damp exploded.

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* The efficiency of wire gauze shields as a protection against flame, was shown in some remarkable experiments performed by Aldini. An avenue of fagots was kindled, and a fireman clothed in asbestos and armed with a large iron wire-gauze shield, ran through the flames, repelling them before him by means of the shield. The non-conducting power of the iron wire temporarily protected his person from the scorching effect of the flame. As an experiment the result was successful. (See Art. 58, p. 23.)

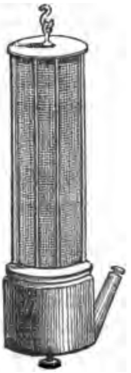
Fig. 164.

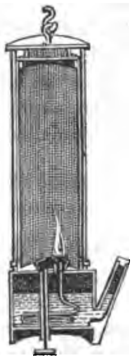
Fig. 165.

Blowers or strong currents of air may act like a blow-pipe on the flame, and cause the point of the flame to heat to redness and traverse the wire gauze. A blast of gunpowder will have a similar effect, but the use of gunpowder in fiery mines is always attended with danger. The safety-lamp under such circumstances can afford no protection.

The efficiency of the lamp and the correctness of the principles on which it is constructed have been established by numerous experiments on mixtures of coal-gas and air. The writer has frequently lowered it into the most explosive proportions of fire-damp and air, with no other effect than that of extinguishing the light, and causing a volume of flame to appear in the interior of the cylinder. The awful destruction of life which takes place yearly from coal-mine explosions may be generally traced, when traceable at all, to carelessness in removing the cage, or making holes in the wire gauze for additional light, the use of tobacco, lucifer-matches, or gunpowder in blasting the coal. The lengthening of the flame should serve as the first indication of approaching danger, and the miner should remove from the spot, and not allow the wire cage to become overheated. In some of the mines of Lancashire it was the custom not only to lock the wire cage to the lamp, but to suspend above the flame an extinguisher by means of fusible metal, so that when overheated, this was melted by conduction, and the flame was extinguished.

"*Heat spreads in fluids chiefly by convection** *or the transference of their particles.*"

610. The reason why the hand judges a liquid like water to be cold, is, that from the mobility of the liquid particles among themselves, those in contact with the hand are constantly changing ; they quickly give place to others, so that there is a constant renewal of particles in contact with the skin. If a finger held motionless in water feels cold, it will feel colder still when moved about : and a man in the air of a calm frosty morning, does not experience a sensation nearly so sharp as if with the same temperature there be wind, or if he himself is constantly changing his position. A finger held up in the wind discovers the direction in which the wind blows by the greater cold felt on the windward side where the shifting of particles is greatest, the effect being still more remarkable, if the finger be wetted and moved about ; the cooling effect of evaporation is then added. If a person in a room with a mercurial thermometer, were with a fan or bellows to blow the air against it, he would not thereby lower the mercury, because it had already the same temperature as the air, yet the air blown against his own body would appear colder than when at rest, because, being colder than his body, the motion would supply heat-absorbing particles more quickly. In like manner, if a fan or bellows were used against a thermometer hanging in a furnace or hot-house, the thermometer would suffer no change, but the hot air blown against the hand of a person would be distressingly painful, like the blasting sirocco of the sandy deserts of Africa. If two similar pieces of ice be placed in a room somewhat warmer than ice, one of them may be made to melt much sooner than the other, by blowing on it with a bellows ; —as we see the accumulated ice and snows of winter so rapidly melting when the warm south winds of spring begin to blow upon them.

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* Convection, from the Latin, *convectio*, signifying the act of carrying or transporting.

In dry air, at rest, the human body can resist a temperature of 250° (Graham). Cold air, considerably below the zero of Fahrenheit, can be easily borne, provided it is not put in motion by winds or currents. In such cases the heat or cold becomes unbearable.

All gases resist the passage of heat by conduction, but the lighter the gas the greater the rapidity of convection and the transportation of heat.

611. Owing to the mobility among themselves of fluid particles, heat entering a fluid anywhere below the surface, by dilating and rendering specifically lighter the portion heated, allows the denser fluid around to sink down and force up the rarer; and the continued currents so established, diffuse the heat through the mass much more quickly than heat spreads by conduction in any solid, hence all liquids should be heated at the lower part.

Perhaps the best experimental illustration of this subject is obtained by dipping a tall glass jar, filled with water in which small particles of sawdust or any other light substance are diffused to show its movements, first in a warm bath, and then in a cold bath. In the warm water the sawdust near the outside of the jar, where it is heated, will exhibit a rapid upward current, while in the centre of the jar, where it still remains cool, it will form an opposite or descending current. In the second case, or when the jar is placed in a cold bath, the direction of the currents will be reversed.

Count Rumford's experiments led him at first to conclude erroneously that liquids, but for this carrying process of the particles changing their place, were absolutely obstructive of heat.

The following experiments will, however, show that water is a very bad conductor. If a thermometer is placed in a jar of water, and a red-hot copper ball is gradually dipped into the upper stratum to cause it to boil violently, the bulb of the thermometer a few inches below is quite unaffected. If ether is poured on the surface of the water and inflamed, the thermometer is unchanged. No heat is conducted downwards so as to affect it.

The most striking proof is to freeze in the lower part of a thin glass tube a quantity of water, and then, grasping the tube with flannel, to boil the water above the ice in a spirit flame. It soon boils, without conveying its heat downwards, for the ice remains unchanged. From this it may be inferred that in the equatorial regions the heat of a tropical sun penetrates only to a slight depth.

Mercury does conduct downwards to some extent; but as this is a metal, it possesses a high conducting power as such. A hot poker, plunged into water, heats only the portion of water which it touches, or which is immediately around it. If plunged into mercury, the whole becomes warm, the heat being rapidly spread by conduction.

The internal currents or circulation produced by heat in fluid masses, and of which there are so many important instances in nature, have been already explained. Changes of temperature are the active causes of winds and other atmospheric phenomena.

612. *Warming buildings by the circulation of hot water.*—The heating of buildings by warm water distributed through iron pipes, depends on this kind of circulation or distribution. The water is heated by a stove placed in the basement of the building, B, and one of the most convenient forms is a welded iron boiler, *a* (fig. 166), in the shape of a stove, the heating material being thus in the centre, and so placed as to impart all its heat to the water through the inner casing. A wrought-iron tube, *b b*, of great strength, and secured to the boiler by a water-tight junction, rises from the top of it and is connected on the different floors with a system of cast-iron pipes, *c c c*, four inches in diameter (a convenient size, as every foot in length then corresponds to a square foot in area), the number of which must depend on the space to be warmed. From the lower part of these pipes, which are arranged so as to favour a flow downwards, there is another wrought-iron tube, which is carried down so as to enter the boiler at the bottom. At the highest point is a narrow pipe for carrying off any steam which may be produced. The boiler itself is connected with a small iron cistern, *d*, placed above the level of all the pipes. This continually supplies water to the boiler by the descending pipe, *e e*. When the water is heated, it rises through the ascending or flow-pipe, *b b*, and gradually heats the water in the cast-iron pipes, *c c c*. As the pipes cool by radia-

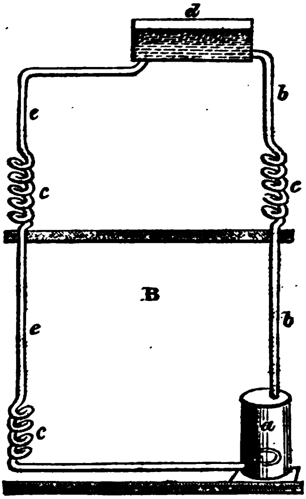

Fig. 166.

tion and convection, the cooled water descends through the return pipe, *e e*, and enters the boiler at the bottom, to be again heated and again circulated.

The writer has for many years used an apparatus of this kind, the water rising to the height of thirty feet from the boiler, and equally warming the water in 160 feet of iron pipes. The highest temperature observed in the water distributed through the pipes was 150°. This system is well adapted for conservatories, halls, and any large spaces which require to be heated to a temperature between 50° and 60°. As the supply cistern is freely exposed to the atmosphere, the temperature of the water in it can never exceed 212°.

613. *Oceanic Currents. The Gulf Stream.*—The distribution of heat in the oceanic waters is a further illustration of these principles. In the Atlantic equatorial regions the water becomes strongly heated, and currents of enormous extent are thus set up, which serve by their circulation to equalize temperature. One remarkable current of this kind issues from the Gulf of Mexico, and is well known as the Gulf Stream. Passing round the peninsula of Florida, it takes a north-easterly direction, and spreads in a vast stratum to the west of the Azores. It is thus found to traverse 3000 miles in about seventy-eight days. The temperature varies according to the latitude, but it is generally 8° or 10° above the temperature of the surrounding sea. It discharges large quantities of heat in its progress over the Atlantic, and its influence in conveying warmth is felt on the coasts of England, Ireland, Scotland, and Norway, and it is even said to be perceived as far north as Spitzbergen. There is a counter-current of cold Arctic water on each side of it, which, according to Dr. Carpenter, buoys it up from beneath. This writer describes the Gulf Stream as a river of superheated water, which widens and becomes more shallow as it proceeds northwards. Off Sandy Hook it is sixty miles in breadth, and it has a depth of 600 feet. Below this there is a considerable stratum of water at a temperature of from 60° to 65°, upon which this warm oceanic river rests. Below this, again, is a deep stratum, 2000 fathoms or 12,000 feet, in thickness, of which the temperature was found to be from 35° to 40°.*

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* Dr. Carpenter estimates from the numerous soundings which have been taken that the general depth of the Atlantic does not exceed three miles. The most remarkable of these, taken in the *Challenger*, gave a depth of 3800 fathoms, or 22,800 feet. As there are 880 fathoms to a mile this is equivalent to 4¼ miles. This sounding was apparently in a deep hole about 100 miles north of St. Thomas, while the *Challenger* was on her way to

This is about the degree at which water reaches its greatest density. The researches of Dr. Carpenter lead to the conclusion that these cold strata in the deep Atlantic, are vast polar currents flowing from the Arctic and Antarctic regions, and supporting upon their surface, and indeed upbearing, the heated waters which issue from the Gulf of Mexico and the equatorial region.* The great Arctic current which underlies the Gulf Stream has a definite movement southwards. This is proved by various facts. Icebergs occasionally cross the Gulf Stream off the Banks of Newfoundland, and are carried to the south of it. This can arise only from the southerly movement of the deeper stratum in which the lower part of the vast mass of the iceberg is immersed, which carries it along against the counteraction of the upper or warm current. A remarkable fact mentioned by Dr. Carpenter confirms this view. The buoy which was attached to the broken end of the Atlantic cable of 1865, having got adrift, was found to have travelled due south nearly a distance of 600 nautical miles in seventy-six days, in opposition to the Gulf Stream, presumably by the action of the underflow upon the long buoy-rope suspended in it.

The dense fogs which are well known to surround Newfoundland, are attributed by some physicists to the meeting of the warm waters of the Gulf Stream with the cold Arctic current proceeding from the north. There are other currents of vast extent in the Atlantic, Pacific, and Indian Oceans, depending on changes of temperature in the water, and the transfer of heat by convection or circulation to restore the equilibrium. These have been well represented by Messrs. Johnston on a hydrographic map of the world : they convey an impressive idea of the vast changes produced by heat in the circulation of oceanic waters.

Bermuda. The crushing of thermometers which had been already used at a depth of 2600 fathoms, proved that the instruments had gone to a much greater depth. Some of the loftiest mountains on the globe might be sunk in this depression without showing any portion above the sea-level.

* In Dr. Carpenter's view, the Gulf Stream issuing through the Florida Channel is entirely a product of the action of the trade winds on the equatorial Atlantic, driving it into the Carribean Sea and the Gulf of Mexico, and then forcing on the current through the Florida Channel, to come out as what is called the Gulf Stream. It has a certain superficial spread, but is a mere surface current.—'On the Deep Sea Bottom.'

The currents produced by heat and cold in the ocean, and in great masses of water generally, maintain in and over them a comparatively uniform temperate freshness, while the rocks and soil on the shores around, may be either parched under a burning sun, or bound up in frost.

614. A keen frost chills, and soon hardens in its icy grasp the surface of the ground; but of water similarly exposed, the part first cooled descends to the bottom by its increased density, and forces up warmer water to take its place and to diffuse heat: this in its turn is cooled and descends, and a continued circulation is established, so that the surface cannot become ice until the whole mass, of whatever depth, has been cooled down to a considerable density. Hence the very deep sea is not frozen, even in the coldest climates; and in temperate climates the severest winter freezes only superficially lakes of ordinary depth. During this internal movement in the water, that which ascends to the surface to be cooled, by losing one degree of its heat, warms more than 500 times its bulk of air one degree, and thus tempers remarkably the air passing over it. Hence, places in the vicinity of the sea and of lakes are warmer in winter than places farther inland, although nearer to the equator. England is much warmer in winter than Central Germany, which lies south of England; and the coasts of Scotland and the north of Ireland may be warmer than London:—snow never lies long upon these coasts. As continental or inland countries have thus in winter an extreme of cold, so have they in summer an extreme of heat. Water admits the rays of the sun, and absorbs the heat into the thickness of its mass, and therefore is warmed very slowly; but the dry earth, because a slow conductor, retains all the heat near its surface, and is therefore soon heated to excess.

615. The ordinary ventilation of our dwellings and places of assembly is owing to the motion produced by the changed specific gravity of air when heated. The air which is within the house, owing to fires, the respiration of inmates, &c., becomes warmer than the external air, and the latter then presses in at every opening or crevice, to displace or force up the other. The ventilation of the person by the slow passage of air through the texture of our clothing is a phenomenon of the same kind; and thicker clothing keeps a person warm chiefly by diminishing the rapidity of this passage. Hence an oiled-silk or other air-tight covering laid on a bed has greater influence in preserving warmth than one or two additional blankets, and is not generally used, only because it prevents ventilation, and, by shutting in the insensible perspiration, soon produces dampness. From the part of the bed-clothes immediately over the person there is a constant outward oozing of warm air, and there is an oozing inward of cold air in lower situations around.

616. The power of fluids to diffuse heat being due thus to their power of *carrying*, and not of *conducting* it, the consequence should follow, that any circumstance which impedes the internal motion of the fluid particles would diminish the diffusing power. Accordingly, we find that fluids in general transfer heat less readily in proportion as they are more viscid. Water, for instance, transfers less quickly than alcohol; oil than water; molasses or syrup than oil: and water thickened with starch or other substances dissolved or suspended in it, or which has its internal motion mechanically impeded by feathers or thread immersed in it, undergoes circulation much less quickly than where it is pure and at liberty. Cooling being merely a motion the reverse of heating, is influenced by the same law. Hence the reason why thick soups, pies, puddings, preserves, and all semi-fluid masses, retain their heat so long—so much longer than equal bulks of water, although they are cool on the surface. The same law affords explanation of the facts, that very porous masses and powders, such as charcoal, metal filings, sawdust, sand, &c., conduct heat more slowly than denser masses,—their interstices being filled with air, which searcely *conducts* heat, and which, by the structure of the substance, has no freedom of motion or circulation by which it might *carry* the heat.

The Heat Transferrer.

617. In reflecting upon the fact that heat is diffused in masses of fluid, not by simple conduction, as in solid bodies, but chiefly by motions or currents among the particles, produced, as above described, by changed specific gravity, and knowing that two equal measures of water having different temperatures, when completely mixed, become a double quantity of an exactly intermediate temperature, the writer perceived the possibility (Art. 331) of causing equal quantities of boiling and freezing water to run past each other, in perfectly distinct although touching channels, in such a manner, that instead of the two becoming of the same middle temperature, the lately boiling should become nearly freezing, and the lately freezing nearly boiling. It seemed strange that this easy operation was not in common use and employed for many important purposes. But it was not unnatural for persons to think that when a measure of hot water had given up half its heat to an equal measure of cold, and had thereby rendered that as warm as itself, no further change could occur. At first one might not think of the consequences of making the currents run in contrary directions and in vertical channels. The adjoining engravings will explain the process.*

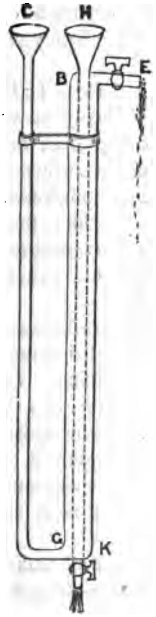

Fig. 167.

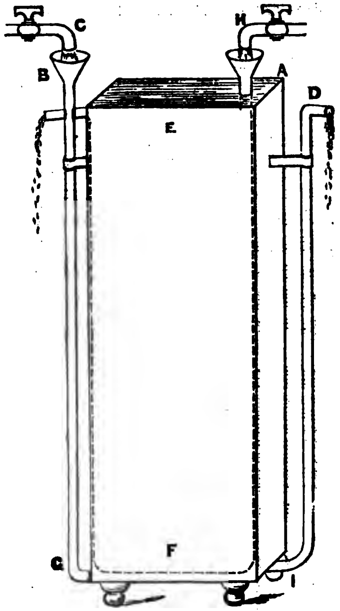

Fig. 168.

Let H K (fig. 167), be a long tube formed of very thin metal, with a funnel, H, at the top, into which boiling water can be poured, to issue again below through the regulating cock, K. Let B G be a larger tube surrounding the other, and just so much larger as to allow an equal current of nearly freezing water coming from the funnel, C, by the tube, C G, to enter below at G, and to rise around the smaller tube, to be discharged through the cock, E. Evidently then, if the tubes be of sufficient length, the lately boiling water descending in the internal tube, H K, must be losing every instant, and at every point in its course, part of its heat, to the colder ascending current around it, until it has lost the whole of its excess, which being all gained by the equal ascending current, the transference becomes complete. It might at first be supposed that great length of tubes would be required in the experiment; but in truth a length of about one yard suffices to prove conclusively the efficacy of the arrangement.

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* The reader will find another form of apparatus for a similar purpose described at p. 197.

Fig. 168 is only a more capacious repetition of fig. 167. In it the channel of the descending hot water, instead of being a single cylindrical tube of narrow surface, through which the heat has to pass from one fluid to the other, has a very extensive surface compressed into small bulk by being corrugated or folded longitudinally upon itself. It so forms many thin flat channels in which the hot fluid descends, while the rising colder fluid occupies similar flat spaces between these; and no particles of the hot fluid can avoid being always close to passing particles of the colder.

Fig. 169 is a section of the parallel columns as viewed from above. The dark spaces mark the hot liquid descending, the light spaces the colder liquid rising. In the larger apparatus, the water which has been cooled is caused to rise from the bottom in the tube, I D, to be discharged conveniently at D, nearly at the level of the other inlets and outlets.

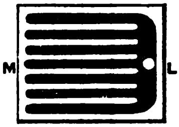

Fig. 169.

Among the purposes which the heat transferrer may serve, are the following :—

1. Cooling at once the hot wort of brewers, instead of having to pump it up as of old, to spread on wide expanded cooling floors, where it loses aroma, and may suffer other damage.

2. To lessen the expense of warm-bathing establishments, and of public wash-houses.

3. To facilitate in winter the complete warm ventilation of dwellings, churches, manufactories, halls of assembly, &c., without danger of cold draught, and with small expense of fuel. The transfer of heat takes place between currents of air as it does from liquid to liquid.

4. To allow the formation of a perfect breath-warmer, important to persons of delicate health, in cold weather.

5. To utilize the warmth of smoke in various ways.

Engineers having familiarity with the principle may suggest many forms and applications.

> " *Heat spreads also, partly, by being radiated or transferred from one body to another, through transparent media or empty space, with a readiness which is modified by the material and the state of the giving and receiving surfaces.*"

618. If a heated ball of metal be suspended in the air, a hand brought in any direction near to it will experience the sensation of heat: and beneath it the sensation would be as strong as on the sides, but that the heat has to meet a current of cool air approaching from below, to rise from it, as explained in a preceding section. A delicate thermometer substituted for the hand will equally detect the spreading heat, and if held at different distances, will prove it to diminish in the same ratio as light diminishes in spreading from any luminous centre, *viz.*, to be only a fourth part as intense at a double distance, and in a corresponding proportion for other distances. If the heated body be enclosed in a perfect vacuum, a thermometer placed near it will still be affected in the same manner; hence no apparent medium is required for the transference of the heat. If a screen be interposed between the body and the thermometer, the latter will not be affected at all, proving that the heat spreads in rays or straight lines. Heat when diffusing itself in this way, is called *radiant* heat, to distinguish it from heat passing by contact or communication, as described in the last section, and, like it, decreasing in intensity according to the square of the distance of the heated solid, *i.e.*, at two feet its intensity is reduced to one-fourth, and at three feet to one-ninth. Fig. 1, page 9, will serve to render this law of decrease intelligible.

619. Radiant heat resembles light in other respects. It rapidly permeates certain substances, such as rock salt, and its course suffers in them the kind of bending termed by opticians *refraction.* It is reflected from polished surfaces, just as light is reflected from a common mirror; and many such surfaces directed to one point or centre, or a single concave surface having its one centre or focus, will concentrate the heat with the light (Art. 566). Its motion in the sunbeam is so rapid, that for any distance at which men can try the experiment, it appears instantaneous; and the rays of heat from hot iron or burning charcoal concentrated at great distances by suitable mirrors, affect a thermometer as quickly as the heat of the sun similarly reflected. The rapidity of its passage is probably as great as that of light, the rays of light and heat from the sun reaching the earth simultaneously. Although light and heat are united in the sun's rays, they are still separable, as by glass prisms or lenses, and by other means; and the focus of heat behind a burning glass is not precisely the focus of light. Heat in radiating through air and transparent liquids does not warm them, and its passage through air is not sensibly affected by winds or any other motion of the atmosphere. These resemblances in the phenomena of light and heat have led to the hypothesis that the two classes of appearances are only different modifications of action in the same subtle substance or ether.

All bodies radiate, whether they are above or below the temperature of the medium in which they are placed.

620. Thus, heat-rays are radiated by a flask of boiling water, by the living human body, by a ball of ice, or of red-hot iron; and this radiation goes on until an equilibrium of temperature is established The diffusion of heat by radiation, as it takes place in an instant to any distance, and is strongly manifested when there is any inequality of temperature between bodies exposed to each other, would produce a speedy balance of temperature throughout nature, but that heat leaves and enters bodies with a readiness depending on the condition of their surfaces, and on their internal conducting powers. A black stone-ware teapot, for instance, filled with boiling water, will radiate away 100 degrees of its heat in the same time that a similar vessel of polished metal will radiate only 12 degrees.

621. Professor Leslie was the first to investigate this subject and to discover many important facts. As common thermometers are not sufficiently delicate to determine very sudden changes of temperature, where the influence is so slight as in many cases of radiant heat, he contrived the beautiful *differential thermometer*, represented in fig. 170, p. 433, in conjunction with concave mirrors, to concentrate the heat and accumulate its energy.* Then taking, as the heated body, a cubical tin vessel filled with boiling water, and covering it successively with plates or layers of different substances and with different colours, and exposing the thermometer to it for a given time under all the changes, he noted the number of degrees which the thermometer rose (as seen in the table which here follows), and thus ascertained the radiating power of each sort of covering.

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* A more delicate instrument of recent invention, called the *thermopile*, will be described in the section on *Electricity*.

Lamp-black	100°	Plumbago	75°
Writing paper	98	Tarnished lead	45
Sealing wax	95	Clean lead	19
Crown glass	90	Iron polished	15
Ice	87	Tin plate	12
Isinglass	75	Gold, silver, and copper	12

He next reversed the experiments by using his hot-water vessel always in the same state, and covering the thermometer bulb with the different substances and colours, and thus he ascertained that the comparative *absorbing* powers of the substances and colours were very nearly proportioned to their *radiating* powers: lamp-black, for instance, absorbed or was heated 100°, while the polished metals absorbed, or were heated only 12°, and so for the others. Lastly, the absorbing powers being an indication of the weakness of the *reflecting* powers (for a body absorbing a given proportion of the heat which falls on it, can reflect only the remainder), he by the same experiments ascertained the radiating, absorbing, and reflective or mirror powers of the bodies, and, therefore, all the important points respecting radiant heat in its relation to different substances. The highly polished metals, owing to their lustre and smoothness, have the lowest radiating power, and it is found that this is not in any way affected by substances placed beneath them. A glass plate covered with gold or silver leaf possesses the radiating power of the bright metals.

It seems paradoxical that a clothing of a thin cotton or woollen fabric placed on a polished tin vessel, should cause the heat to be received by it or dissipated from it much more than if the vessel were naked and polished, but such is the fact. A metal with its surface scratched or roughened radiates or receives heat much more rapidly than highly polished metal.

622. The property of absorbing radiant heat was supposed to depend in some measure on the *colour* of the substance. As a general rule, the dark colours, *i.e.*, those which absorb the most light, absorb also most heat, especially solar heat. Tyndall found that white in some cases exceeded black, black in some cases exceeded white, and the other colours were equally capricious, all evidently depending on the constitution of the substances. Radiation and absorption were however in all cases found to go hand in hand—the substance which absorbed heat most powerfully radiated the same heat most copiously.

Franklin placed pieces of cloth of different colours on snow, and exposed them during a given period to the sun's rays—noting the different depths to which the cloths sank by the melting of the snow beneath; but it has been justly remarked of these experiments that the luminous rays of the sun are alike powerless to warm the cloth or to melt the snow. Whatever effect is produced is therefore owing to the dark solar rays which snow rapidly absorbs; these are also absorbed by dark-coloured cloth.

The more recent experiments of Dr. Bache lead to the inference that the radiating power of any surface is not materially affected by its colour, so that the colour of clothes worn during winter, has no marked influence in retaining warmth. The absorbent power is, however, entirely dependent on colour, so far as solar heat is concerned.

Many animals in the polar regions are remarkable for having a white fur, but the retention of heat in them is owing to other conditions, and not to the mere absence of colour. Animals with dark fur are also found in these regions.

623. Those surfaces which radiate heat freely also absorb it readily, and thus the best absorbers of heat are found at the top of the table, page 431. The bright metals at the lower part of the table absorb but little. They are, however, powerful reflectors, as a proof of which it may be stated that while reflecting to a focus heat sufficient to ignite phosphorus (113°), the surface will be found quite cold. If highly polished, they do not retain enough to convey to the hand the slightest sensation of warmth. Glass reflectors, owing to the metallic surface being behind a certain thickness of glass, retain a portion of the heat and become sensibly warm.

There is a difference among metals in the power of reflecting heat rays. According to Melloni, out of 100 rays, silver reflects 90, bright lead, 60, and glass, 10.

The rate of cooling in heated bodies is influenced by all the particulars noted above, *viz.*, substance, surface, and colour, and by the excess of heat in the cooling body as compared with those around it.

624. The concentrating apparatus used for experiments on the radiation of heat consists of two concave highly polished tin mirrors, here represented at *a* and *b* (fig. 170), so formed and placed in relation to each other, that all the rays of light or heat issuing from the focus of one, as at *c*, shall, after a double reflection, be collected in the focus of the other, *d*. A stand under one focus, *c*, is intended to support the body giving out or receiving heat, and a stand under the other, *d*, supports the thermometer. For further explanation of the action of such mirrors we may refer to the section of *Optics*, on the concentration of light. The laws of heat reflection are precisely the same as those for the reflection of sound, already referred to in the last section, Art. 500. Now the surface of a spherical concave acts so that every ray issuing from a point which is not the centre of the said concave, but half-way nearer the surface, shall, when reflected, become parallel to every other ray—as represented by the dotted lines in the figure; and it is the property of a similar mirror receiving parallel rays, to make them all meet in that focus:—thus, any influence radiating from *c* towards the mirror, *a*, will again,

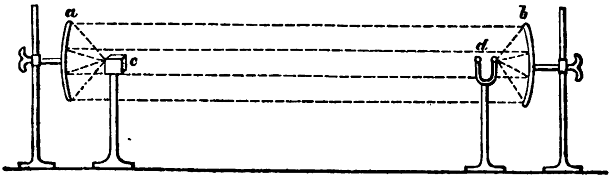

Fig. 170.

after two reflections, be collected at *d*. (See also Art. 501.) To show their effect and mode of action, they may be placed exactly facing each other at any convenient distance, while a hot body of any kind, as a metallic ball or a canister of boiling water, is placed in the one focus, and a thermometer in the other, the thermometer will instantly rise; although if left in any intermediate situation nearer to the hot body, and therefore not in the focus, it will not be sensibly affected. If burning charcoal, or a red-hot copper ball, be placed in one focus, and a readily combustible substance, like phosphorus, in the other, the latter may be heated so as to melt and take fire at the distance of thirty feet or more.

If in one focus of the mirror-apparatus described above, there be placed, instead of the canister of hot water, a block of ice, the thermometer in the other focus immediately falls. This was formerly described as the radiation of *cold*, and persons were at one time disposed to think that it proved cold to be a substance of a different nature from that of heat. The case, however, is merely that the thermometer happens then to be the hotter body, in one focus of the mirrors, brought into close relation with a colder body, the ice, placed in the other, and consequently, by the law of equable diffusion or exchanges, it must share its heat with the ice, and this will cause the thermometer to fall. The mirrors in any case exert their effect merely by preventing the spreading and dissipation of some radiant heat from either focus except towards the other, and of making two distant bodies act upon each other as if they were almost in contact, or very near. All the heat that seeks to radiate from the thermometer, *d*, in the direction of the surface of the mirror, *b*, if not met by an equal tension or force of temperature in the other mirror or focus to which they are directed at *a* and *c*, will radiate away to *c*, and become deficient at *d*, hence it is considered that an incessant interchange is taking place among bodies which are near to each other until an equalization of temperature is reached. This happens when every body radiates as much heat as it receives.

If a flask of water at 212° is placed in one focus, and a block of ice in the other, the ice will receive a larger portion of heat rays than it emits, and will show this by rapidly melting. If for the ice we substitute a red-hot copper ball at 1100°, the water will now appear to receive the heat from the ball, but it does not the less radiate heat. The difference is not so great between ice, at 32°, and water, at 212°, as between the latter and a metallic ball heated to redness.

625. Different substances allow a passage to rays of light more or less readily, and accordingly are said to have different degrees of transparency, as in the series from pure air, glass, water, &c., at one end, to paper, thin porcelain, stones, &c., at the other; so different substances influence very differently the passage of the rays of heat. But, what might not be expected, certain substances which transmit light freely are found to obstruct heat, as crystals of pure alum, while some which obstruct light, as a kind of black glass, used for the polarization of light by reflection (see section on *Light*), give free passage to heat. Another remarkable fact is, that heat from a source of great intensity, like the sun, passes readily through many substances,—as glass, water, and even ice, which absorb and arrest heat-rays from sources of lower temperature, as hot stones or liquids. Rock salt has the remarkable property of allowing the heat-rays of both kinds, solar and artificial, to pass through it with equal readiness.

It is important to remark here that because water or moisture in the air offers considerable obstruction to the passage of heat-rays from sources of low temperature, the state of the atmosphere as to moisture near the surface of the earth, influences much the temperature existing there. The sun's heat-rays come down readily, not only through the dry atmosphere of great elevations, but also through the humid air below; while the return upward by radiation from the moderately heated earth, is resisted by the presence of moisture, and a useful warmth is retained below. Unimpeded radiation, through perfectly dry clear air during a single night might chill ordinary vegetation very destructively. Dr. Tyndall has directed the attention of physicists to this fact.

626. In our drawing-rooms it is common to have plate-glass fire-screens, which, while they allow the light to pass, defend the face from the heat: but all persons know that the heat of the sunbeams, as well as their light, enters our green-houses through the glass which covers them.

Hence, bodies which are transparent to light, or *diaphanous*,* are not in the same proportion transparent to heat, or *diathermanous*.† Plates of equal thickness and of equal transparency to light, allow very different quantities of heat to traverse them. Out of 100 incident rays of heat from an Argand oil-lamp, it was found, in accordance with what is stated above, that while alum allowed only 12 rays to pass, rock-salt was traversed by 92; rock crystal and Iceland spar by 62; and gypsum by 20. Rays of heat may be so concentrated as to ignite a fragment of phosphorus at their focal distance. If a screen of rock-salt is interposed, the phosphorus is equally ignited; but if alum is substituted, this arrests the rays of heat, and the phosphorus does not take fire. Both may be equally transparent to light, but the result shews that one transparent substance is easily traversed by heat, while another obstructs its passage. Rock-salt transmits heat from all sources, and of all degrees of intensity; but of all transparent bodies water is that which admits the smallest number of heat-rays to traverse it.

Faraday determined the amount of heat-penetrating power in various kinds of glass, by placing behind equal surfaces, sheets of white blotting-paper soaked in ether. The rapidity of evaporation formed a criterion of their *diathermanous* properties; and he came to the conclusion that a pale green glass was best fitted for conservatories, by reason of its allowing the light to traverse, but to a certain extent arresting the heat-rays.

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* From δια, through, and φαινω, to appear.

† From δια, through, and θερμη, heat—heat penetrating.

627. A glass screen interposed between the two concave mirrors in the apparatus above described, destroys almost entirely the effect of the heated body placed in one focus, on the thermometer in the other, and the trifling effect really produced, appears to be owing to the heat that is absorbed by one side of the screen, and then, after passing through it by conduction, is radiated from the other. This conclusion is supported by the fact that screens of metal or of glass, covered with lamp-black, paper, &c., allow transmission nearly in proportion to their several absorbent and radiant powers.

The doctrine of radiant heat makes us aware of the importance of having vessels of highly polished metal for containing liquids or other substances which we desire to keep warm; hence tea and coffee-pots, &c., should always be highly polished. Pipes for the conveyance of steam or hot air, if left naked, should be of polished metal so long as they are intended to contain steam; but after arriving at a place where they have to give out their heat, as in the hot-water warming apparatus, their surface should be blackened and made rough. A mirror intended to reflect heat should be of highly polished metal, and such, for an obvious reason, the interior of a screen placed behind roasting meat at a kitchen fire, should be. A fireman's helmet is usually made of highly polished metal. It is of advantage that the bottom of a tea-kettle, or other cooking vessel, be externally black, because the bottom has to absorb heat, but the top should be polished, because it has to confine it.

628. *Formation of Dew.*—The interesting phenomenon of *dew* was not well understood until the laws of radiant heat had been investigated. At sunrise, in particular states of the sky, every blade of grass and leaflet is found, not wetted, as if by a shower, but studded with lustrous and transparent globules of water, bending it down by their weight, and falling like pearls when the blade is shaken. These are formed in the course of the night by a gradual and slow deposition on the leaves of vegetables and other bodies, rendered by radiation colder than the air around them, of part of the aqueous vapour which rises invisibly into the air during the heat of the day. In a clear night the objects on the surface of the earth radiate heat to the sky through the air, which impedes but does not altogether prevent radiation, while there is nothing nearer than the stars to return radiation. The substances thus radiating heat consequently soon become colder; and if the air around has its usual proportion of moisture, part of this will be deposited on them in the form of dew, exactly as the invisible moisture in the air of a room is deposited on a cold bottle of wine when first brought from a cool cellar and placed on the table. Dew is, therefore, essentially a deposit of condensed aqueous vapour on solids cooled below the temperature of the surrounding atmosphere. Dr. Wells was the first to give a correct explanation of this phenomenon.

629. Spring and autumn are the seasons in which the greatest difference is observed between the temperature of the day and night, and between the temperature of the earth and the air covering it, as the result of radiation. At this time of the year the earth will be sometimes cooled by radiation to 20° below the temperature of the air which covers it. It is this great difference suddenly occurring which leads to the separation of aqueous vapour, sometimes in the form of thick fogs, at others in the shape of dew. In winter, when the thermometer is at or below 32°, the deposited particles of water assume a crystalline arrangement around the twigs of trees, which is well known as hoar-frost.

The deposition of dew and hoar-frost may be easily imitated. Place in a large glass flask five ounces of strong hydrochloric acid, and add to this eight ounces of powdered sulphate of soda, rapidly mixing and shaking the mixture to promote solution. In a few minutes the air surrounding the flask deposits its moisture, rendering the surface dull, and in a quarter of an hour or less the liquid becomes frozen, and soon forms a thick crust of hard snow on the glass. The beauty of the effect produced by hoar-frost is in the slow formation of perfect hexahedral crystals of snow interleaved with each other, and giving a sparkling lustre to the twigs of trees on which they are deposited. These crystals are in fact frozen dew. (See Illustration, p. 409.)

630. Clouds obstruct radiation from the earth; in other words, they reflect and return the heat radiated; and thus on cloudy nights the deposit of dew does not take place. For a similar reason, cloudy nights in winter are generally warm nights. On the other hand, the effect of clouds in summer, or during the day, is to lower the temperature, because at this time the earth receives more heat from the sun than it radiates, and the access of this heat to the earth is thereby cut off. It is on warm clear nights in the evenings of autumn, that the dew is most abundant.

In the tropical climate of India, radiation from the earth during a single night takes place to such a degree as to freeze a thin stratum of water placed in a shallow pan and sunk a short distance into the ground. At Calcutta, the temperature of the air rarely falls below 40° on the coldest nights. During the Prince of Wales's recent visit to India it was observed to fall on one night to 29°. Owing to radiation through a clear sky, the water is often frozen under these circumstances. In this way ice is still obtained in some parts of India.

Air itself seems to lose little heat by radiation. A thermometer placed upon the earth any time between sunset and sunrise, generally stands considerably lower than another suspended in the air a few feet higher up, owing to the great radiation of heat upwards from it and from the earth, while the surrounding air remains nearly in the same state. During the day, while the sun shines, the earth is much warmer than the air, but during the night it is cooler, as well as all the substances resting upon it. The best radiators, such as loose straw or sticks lying on the ground, the pointed leaves of grass, decayed leaves, &c., the slender twigs of shrubs and trees, receive the deposit most readily from the atmosphere by their being cooled so much below it. Woollen cloth is a much better radiator than polished metal. It will therefore fall by radiation to a much lower temperature, and will have much more dew deposited on it, than the metal. The reason why the dew is deposited so much more copiously upon the soft spongy surface of leaves and flowers, where it is wanted, than on the hard surface of stones and sand, where it would be of no use, is therefore to be ascribed to the difference in their radiating powers. There is no state of the atmosphere in which artificial dew may not be made to form on a body by sufficiently cooling it, and the degree of heat at which the dew begins to appear is called the *dew-point*, being an important particular in the meteorological report of the day.

631. The proportion of aqueous vapour in air is subject to variation according to temperature. The air is said to be saturated when it contains as much as it can receive at the observed temperature. If cooled below this point, some of the vapour will be separated from it according to circumstances in the form of cloud, fog, or rain. At 52°, air retains $\frac{1}{86}$th of its volume of vapour, and at 32° it retains only $\frac{1}{150}$th of its volume. The more it is saturated the more rapidly is the vapour deposited.

Substances protected from radiation by slight coverings placed over them, retain their temperature, or are not cooled to a degree to allow of the deposit of any liquid upon them. Hence they present no appearance of dew. Gardeners thus protect young and tender plants by covering them with glass frames.

632. The temperature of the surface of the earth, depends on the quantity of heat transmitted to it from the sun, through the clear atmosphere, which absorbs but little. The heat thus received is again lost, chiefly by radiation into space, and, to a very small extent, by conduction downwards through the superficial strata. It is from the amount lost by radiation towards the cold, sunless sky, that we learn the temperature of the medium in which our globe is floating. The lowest natural temperature hitherto observed on the earth, was noticed by Erman at Yakutsk in Eastern Siberia. In January, 1829, this philosophical traveller found that the thermometer fell to 72° below the zero of Fahrenheit, or 104° below the freezing point of water! According to the laws which regulate the diffusion of heat, space must be at or below this temperature, and were there not an annual compensation derived from the sun, the surface of the earth, notwithstanding the existence of subterranean heat, would be speedily cooled to a temperature which would lead to the destruction of all animal and vegetable life.*

Other very low temperatures on the earth have been noticed. Ross, in one of his northern expeditions, met with a temperature of – 60°; and at Nijne Kolymsk in Siberia, in the winter of 1821, the thermometer is stated to have fallen to – 65°. Sir E. Belcher, while wintering in Wellington Channel in 1854, experienced a temperature of – 55°; and in January following, a temperature of – 62°. Dr. Kane on one occasion observed that the thermometer fell to – 68° F. Captain Back at Fort Reliance met with a still lower temperature, – 70°, or 102° below freezing.

It may be here mentioned that Fourier and Schwanberg have calculated the temperature of space in which our planet moves at from – 58° to – 76° F.

> "*Each particular substance, according to the nature and arrangement of its ultimate particles, takes a certain quantity of heat (said to mark its* CAPACITY) *to produce in it a given change of temperature or calorific tension.*"

633. A pound of water, for instance, that its temperature may be raised one degree, takes thirty times as much heat as a pound of mercury. This may be proved in various ways. First, if the heat be derived from any uniform source, the water must remain exposed to it thirty times as long as the mercury. Secondly, if both substances, after being equally heated, are placed in ice until cooled to the freezing point, the heat which escapes from the water will melt thirty times as much ice as that which escapes from the mercury. Third, when a pound of hot water is placed with a pound of cold mercury, instead of the two becoming of a middle temperature, as is the case when equal quantities of hot and cold water are mixed, and every degree of heat lost by the one quantity becomes just a degree gained by the other—the pound of hot water, by giving up one degree to the pound of cold mercury, raises the temperature of the latter thirty degrees; and in the same proportion for other differences:—or on reversing the experiment, a pound of hot mercury will be cooled thirty degrees by warming a pound of water one degree.

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* Yakutsk is in latitude 61° 55′ North. For two months in every year it has a temperature of – 40° F., hence at this time mercury is a solid metal. A custom is said to have existed formerly of presenting to the governor of the city, on the setting in of the severe cold, an image of a saint in solid mercury, the metal being for this purpose poured into a mould and exposed for a night.

To put this in a practical shape, if equal measures of water at 70° and of mercury at 130° are mixed, the resulting temperature will not be the mean (100°), but only 90°. In this case, therefore, the mercury loses 40°, while the water gains only 20°. This refers to equal bulks of the two liquids. When we make the comparison by weight, which is more convenient, we find that a pound of water absorbs thirty times more heat than the same weight of mercury. The capacity of water for heat is therefore to that of mercury, as 30 to 1, or 1000 to 33, and it is usual thus to express the capacities of bodies for heat by a series of numbers having reference to water, as 1000, such numbers representing what are called *specific heats.*

634. Each particular substance in nature has, like water or mercury, its peculiar capacity for heat or its specific heat; and experiments, made by such modes of mixture and of melting ice as above described, have led to the construction of tables which exhibit these relations. The following table shows the comparative capacities of equal weights of some common substances. Water, of which the capacity is greater than that of any other substance except hydrogen, for reasons of convenience, has been chosen as the standard of comparison. It appears that a pound of hydrogen gas takes about three and a half times more heat to produce in it a given change of temperature than a pound of water, while a pound of mercury or gold takes about thirty times less.

The comparative quantities of heat required to raise equal *weights* of different substances through the same range of temperature, are commonly expressed in a tabular form. Water is taken as the standard of 1000 :—

Water	1000	Zinc	93
Alcohol	620	Iron	11
Ether	520	Silver	56
Olive oil	438	Mercury	33
Charcoal	241	Lead	29
Oil of turpentine	462	Hydrogen gas	340
Sulphur	188	Common air	24
Glass	117	Oxygen	22

[These numbers are given differently by some authorities.]

635. *Specific Heats.*—If we seek a reason or reasons why there should be among bodies the differences of capacity here stated, the circumstances chiefly attracting attention are the following: 1st. Equal weights of the various substances have very different bulks or volumes, and therefore seem to have different room in which (if there be a compressible elastic medium concerned, Art. 555) the heat may be received or oscillations of particles may play ;—as a pound of mercury, for instance, is only one-thirteenth and a half as bulky as a pound of water. That the bulk, however, is not the only influencing circumstance appears in the fact that mercury has but one-thirtieth of the capacity of water. 2nd. In equal bulks of different substances, the space may be more completely occupied by the particles of one than of another—as is probably true of the particles of mercury compared with those of water. The influence of bulk or volume, in determining the capacity for heat, is shown in many other facts. In the table, for instance, it is seen that hydrogen and the gases generally, with their great comparative bulk, have also great capacity; that liquids have less capacity than gases; that solids have less than liquids. Yet the capacity is not in strict proportion to bulk; for hydrogen, which is many thousand times more bulky than an equal weight of water, has only three and a half times the capacity. Then, if any body whatever be suddenly compressed into less bulk, heat escapes from it as if it were squeezed out. Thus iron or other metal suddenly condensed by the heavy blow of a hammer is thereby rendered hotter. Water and alcohol on being mixed, occupy less space than when separate, and there is from the mixture a corresponding discharge of heat. This truth is most remarkably exemplified in gases, owing to their great range of elasticity. They may be condensed or dilated a hundredfold or more, and there will be a simultaneous concentration or diffusion of their heat; that is to say, the production, in the space occupied by them, of intense heat or cold.

636. Many mineral waters contain carbonic acid, which remains in tranquil combination while the water is bearing a certain pressure underground, but which in part escapes as soon as the water issues to the air and has only the atmospheric pressure to bear: such waters are called sparkling waters. The reason that champagne and the aërated waters are so cool when first decanted is, that their carbonic acid, in assuming its gaseous form, absorbs, as latent heat, a proportion of the sensible heat which was previously existing in the liquid.

If a gallon of air at the surface of the earth contain a certain quantity of heat, that heat is diffused equally through the space of the gallon; and if the air be then compressed into one-tenth of the bulk, there will be ten times as much heat in that tenth as there was before; an increase affecting the thermometer. In like manner, if by taking off pressure the gallon be made to dilate to ten gallons, the heat will be in the same degree diffused, and any one part will be colder than before.

The heat of air just condensed, or the cold of that which has just expanded, is greater for the instant than the most quickly answering thermometer indicates, for there is so little heat, even in a considerable volume of air, that the mass of a mercurial thermometer absorbing a great part of it would be but little affected. The extent of the change of temperature, however, is seen in the facts, that by the sudden condensation of air we may produce a red heat (1000°), and set fire to tinder immersed in it, and, conversely by allowing air suddenly to expand from a highly condensed state, we may convert any watery vapour diffused through it into ice or snow. It might be expected that air suddenly compressed into half its previous volume, should become just twice as hot as before, or if suddenly dilated to double volume, should be only half as hot; but the facts do not accord with this anticipation, as will be stated in a future page.

The different capacity of air (for heat) in different states of dilatation, produces effects of great importance in nature as well as in the arts—thus,

637. On the surface of the earth near the sea-shore, the air of the atmosphere has a certain density—a cubic foot weighs about one ounce and a third—dependent on the weight and pressure of the superincumbent mass acting on its elasticity; but on a mountain top 15,000 feet high, where nearly half the mass of the atmosphere is below that level, the air is bearing but half the pressure, and consequently any quantity of it has nearly twice the volume of an equal quantity at the sea-side, with a temperature many degrees lower.

On the other hand, the air forming the bottom of the atmosphere, owing to its condensation by the weight of the air above it, is much warmer than if it were suddenly carried higher up, to where, from the pressure being less, it would be more expanded or thinner. Accordingly the height of mountains may be roughly estimated by the difference of temperature observed at the bottom and at the top. While a thermometer stands at 60° at the bottom of St. Paul's Cathedral in London, another marks only 58° at the top of the dome; and in the lofty ascent of a balloon, the thermometer soon falls to the freezing point and even below it, the cold to the aëronaut becoming almost insupportable. Alexander von Humboldt, from a number of observations made on the steep declivities of the Andes near the equator, concluded that the thermometer falls one degree Fahrenheit for every 343 feet of ascent. Dr. Joseph D. Hooker, from observations made in East Nepaul and at Calcutta, deduced a fall of one degree Fahrenheit for every 309 feet of elevation.

638. In every part of the earth, at a certain elevation in the atmosphere, differing according to the latitude or proximity to the equator, the thermometer is found to stand always below the freezing point. This limit in the atmosphere is called the line or level of perpetual congelation or of *perpetual snow*. This line in the equatorial regions of South America, is at the height of 18,300 feet. On the north side of the Himalaya Mountains it is found at the height of 16,625 feet, and on the south side at the height of 12,980 feet.* In Switzerland the snow line is at 8,900 feet, in Spain and Italy at 7,000 feet, and in Norway (lat. 71°) 2,400 feet. In the Alps it is 700 feet lower on the northern than on the southern side. In the Himalayas, as above stated, this condition is reversed. In no part of Great Britain do the mountains reach the line of perpetual snow, which would correspond in this latitude to 4,500 feet. We see, therefore, that snow-capped mountains exist near the equator as well as near the pole. It is this effect of elevation which renders many of the tropical regions of the earth not only tolerable abodes for man, but as suitable as any others; contrary to the opinion of the ancient philosophers of Europe, who deemed them, by reason of the great heat, an everlasting barrier, as regarded man, between the northern and southern hemispheres.

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* On the north side of the Himalayas there is varied cultivation, with good crops, at the height of 13,000 feet, and Captain Gerard found vegetation in full activity at an elevation of 16,800 feet in lat. 32°, while on the southern side it hardly reached 10,000 feet. The birch tree grows at 14,000 feet on the north side, and the oak at 11,500 feet on the south side. (Berghaus.)

639. Much of the tropical land of America is so raised, that, as to agreeable temperature, it rivals any European climate; while the lightness and purity of the air, and the brightness of the sun, add much to its charms. The vast expanse of the high table-land of Mexico is of this kind, enjoying the immediate proximity of the sun, and yet, by its elevation of seven thousand feet above the level of the sea, possessing the most healthful freshness. The land in many parts has the fertility of a cultivated garden, and can produce naturally nearly all that the powers of vegetation can bring forth over the diversified face of the globe. The plains of Columbia, in South America, and others along the ridge of the Andes, are similarly circumstanced. The contrast is very striking, after sailing a thousand miles up the gentle slope of the river Magdalena, in a heat scarcely equalled elsewhere on earth, and surrounded by the animal and vegetable forms which can exist only in such a climate, at once to climb to the table-land above, where *Santa Fé de Bogota*, the capital of the republic, commands a view of interminable plains, that bear the livery of the fairest fields of Europe!

640. Persons not understanding the law which we are now illustrating, will express surprise that wind or air blowing down upon them from a snow-clad mountain, should still be warm and temperate. The truth is, that there is just as much heat existing in an ounce of the air on the mountain-top as in the valley: but above, the heat is diffused through a space perhaps twice as great as when below, and therefore is less sensible. It may be the very same air which moves as a warm gale over a plain at the foot of a mountain,—which then rises and freezes water on the summit—and which in an hour after, or less, is playing among the flowers of another valley, as warm and as genial as before.

As the temperature in different parts of the atmosphere is in fluenced thus by the rarity of the air, and the rarity by the height, the vegetable productions of each distinct region or elevation are of a distinct character; and other peculiarities of place and climate are owing to the same cause.

Because the atmospheric pressure determines the temperature of the air in different situations, as now explained, it has also a corresponding influence upon the state of aërial humidity, which is modified by the temperature.

641. It was explained at Art. 581 that water and other liquids, under a vacuum, rise in the form of air or vapour, with force and in quantity having a strict relation to temperature—heat being in fact the cause of their rising; and the table at Art. 687 exhibits the force, and therefore the density of watery vapour corresponding to certain temperatures. Now it is a remarkable circumstance, that vapour in the same quantity and of equal tension rises from any liquid, whether placed under the pressure of air, or where there is no air, with this difference, however, that through a space containing air it diffuses itself more slowly than if the air were nôt present. As regards the case of rising in air, it was for a long time supposed that the air dissolved the liquid as a liquid dissolves a salt; but it is now generally admitted that there is merely a mechanical mixture of the two gaseous fluids. If the vapour, while rising from a liquid, has not a tension or elastic force equal to the pressure of the atmosphere, the process is tranquil, and is called *evaporation*, and it goes on only as the vapour can diffuse itself among the particles of the air, and therefore slowly in air perfectly quiescent, but quicker as the air is moving more, or as the density of the air is less. But when the vapour, owing to greater heat, is strong enough to overcome the atmospheric pressure of fifteen pounds per inch, and the weight of any liquid over it, the phenomenon of *boiling* arises as already described.

642. For the reason now explained, the air of our atmosphere contains diffused through it a large quantity of invisible aëriform water; and if there were no intestine motions, and no changes of temperature in the atmosphere, the quantity of water would soon everywhere reach a *maximum*, or would be the greatest that the temperature of the place could support. Instead of this, however, from a variety of causes, the air is moving about constantly as winds, and the local temperatures are ever fluctuating, and when the temperature sinks, in a situation where a maximum of watery vapour is present, part of this is instantly reduced to the state of water again (see Art. 631); while to supply material for these phenomena, evaporation is going on wherever, over water, there is not a *maximum* of vapour in the air. These opposing operations of evaporation and condensation keep up that constant distribution of moisture which may be called a part of the life of nature.

643. When a given quantity of water assumes the aëriform state, it takes in and renders latent the same quantity of heat in all cases, *viz.*, six times as much as would heat the water from the freezing to the boiling point, whether rising, for instance, from a boiling caldron, or from the surface of a cool lake. Hence we see why evaporation is so cooling a process to any liquid or moistened solid from which it is rising: and as we have already shown that a rapid passing of dry air over such substance, or the placing it in a vacuum, quickens evaporation, we now see why both of these conditions accelerate the cooling. Wet linen placed in a strong wind, which does not contain a maximum of moisture, becomes dry almost immediately. A bottle of wine covered with a wet cloth and suspended in a current of air, as is practised in warm climates to prepare wine for the table, is quickly cooled; mats hung around the walls of houses in India, and frequently wetted through the day, preserve a pleasing freshness in the apartments. Sprinkling water or vinegar over a hot sick-room cools and refreshes it; and watering the streets of a city moderates in them the intensity of summer heat. In warm climates, water is cooled for drinking by being put into vessels so porous that the external surface is always moist and giving off vapour, the vessels being then suspended in a current of air, or during a calm being made to vibrate in the manner of a pendulum. Again, the rapidity of evaporation from water under the exhausted receiver of an air-pump, and particularly when some other substance which powerfully absorbs watery vapour is included in the receiver, is so great, and carries off the heat so quickly, that the mass of water freezes before much of it has been carried away. This process is used for making ice in India.

644. It is partly because air saturated with moisture, that is to say, having as much water diffused in it as can be supported in the invisible or aëriform state at the existing temperature,—lets fall a part on any reduction of the temperature, that the air of any portion of the atmosphere which has been heated by the sun during the day, and has received much moisture, lets part of that fall again during the night, and exhibits the night fogs of certain seasons, which fogs float upon the surface of the earth, until again acted upon by the beams of the next morning's sun. Fog, when farther condensed, by groups of the minute particles uniting, forms rain; and rain when cooled to 32° becomes snow or hail.

645. A phenomenon which may be classed with dew is the moisture or dampness seen on massive walls and furniture, when with change of weather a warm moist air of higher temperature than the walls suddenly comes upon them. There is a like result when a crowd assembles in a cold church, of which the walls or other solid objects then, from not having yet acquired the new temperature of the surrounding air, condense upon themselves a copious deposition of the breath moisture. For a similar reason a decanter of wine brought from a cold cellar or from an ice-pail, into a room with company, is soon covered with thick moisture or dew; as are the glasses also into which the cool wine is poured. It is still another phenomenon of the same kind, when we see the moisture of warm breath condensed on any cold polished surface, as on the face of a mirror, or on the glasses of a carriage shut up, or on the windows of a room in winter. When the surface of a window pane is very cold, the moisture freezes on it with the appearance of beautiful arborescence. This is owing to the crystallization of the deposited water as it passes from the fluid to the solid state.

646. Many instruments have been contrived, with the name of *hygrometers*,* for indicating the quantity of water in the atmosphere. A prepared human hair forms part of one of those formerly used; the lengthening or shortening of the hair, according to the quantity of moisture absorbed into it, is caused to move an index like that of a wheel-barometer, to mark the degrees. This, however, and other common hygrometers, are only philosophical toys; but Professor Daniell, in his 'Meteorological Essays,' described a correct and simple instrument for the purpose, depending on the formation of dew as explained above. The explanation in a few words is, that when the temperature of a body in the atmosphere falls below that at which the quantity of watery vapour in the air around it can be maintained in the aëriform or invisible state, dew forms on the body.

647. *Daniell's hygrometer* consists of a bent tube with two bulbs containing ether vapour, and in one bulb liquid ether in which a small thermometer is immersed. By causing ether to evaporate from the exterior of one bulb, the liquid ether is cooled in the other and at a certain point, called the *dew point*, this bulb receives a thin film of aqueous vapour from the cooled air around it. The temperature of the liquid ether, is indicated by the thermometer immersed in it. This bulb is darkened in order that the deposited vapour may be rendered more visible. The temperature of the air is at the same time observed, and the greater the difference, or the lower the degree before the deposit of moisture takes place, the dryer the atmosphere.

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* ὑγρος, moist, and μετρον, a measure.

648. The *Wet-bulb thermometer* is also used as an hygrometer for determining the dew point or the dryness or dampness of the air. It consists of two thermometers joined together and equally graduated. The bulb of one is covered with some material which can imbibe and hold water, while the bulb of the other is freely exposed to the air. The wetted bulb is of course exposed to cooling by evaporation, owing to which the mercury in this bulb sinks to a lower degree than in the other. Before wetting the bulb the thermometers should stand at the same degree. By exposure for a few hours such an evaporation and cooling will have taken place that the mercury in this thermometer will have fallen below the other, and the difference marked, will depend on the degree of moisture in the air. If there is no difference it will show that the air is saturated for that temperature, and there has, consequently, been no evaporation. If there is a difference of 10° or 12° it will show that the air is comparatively dry. This instrument is a useful adjunct to the barometer in judging of the probability of the fall of rain.

649. A great fall of the barometer marks a diminished pressure in the atmosphere around, with a consequent dilatation of the air and fall of temperature, as explained in a former part of this work; and if the air at such a time hold a maximum of moisture, a part of this must become visible as fog or rain. Thus a fall of the barometer, a fall of temperature, and a fall of rain, often occur as associated phenomena.

Illustrating this by experiment, we find, that on the extraction of common air from the receiver of an air-pump, a thin cloud or mist generally appears in it with the first strokes of the piston :—the reason being that the still remaining air, because cooled by the rarefaction, absorbs heat from the invisible vapour in combination with it, and renders the water visible. The mist may then be removed by the continued action of the machine, or may be re-dissolved by the usual quantity of air being re-admitted.

We understand from this why rain happens much more frequently among mountains than on extended plains. When air saturated with moisture approaches a mountain ridge to rise over it, for every foot that it rises, it escapes from a degree of the pressure which it bore while lower down, and in then dilating, it becomes colder, and lets fall part of its moisture. It is the rain copiously produced in mountainous regions from this and other causes which constitutes the supply of the many rivers there, and which, with periodical changes of wind, occasions the extraordinary annual overflowing of such rivers as the Nile and the Ganges.

650. Those who have visited the Cape of Good Hope, will recollect a striking phenomenon illustrative of our present subject, observed there when the wind blows from the south-east. Cape Town and the bay in which ships anchor are on the west side of the Cape. Beyond the city, as viewed from the bay, there is a mountain of great elevation, called from its extended flat summit, the Table Mountain. In general its rugged steeps are seen rising in a clear sky; but when the south-east wind blows, the whole summit becomes enveloped in a cloud of singular density and whiteness. The inhabitants call the phenomenon the spreading of the tablecloth. The cloud does not appear to be at rest on the hill, but to be rolling rapidly onward; yet to the surprise of the beholder, it never descends, for the snowy wreaths seen falling over the precipice towards the town below, vanish completely before they reach it, while others are formed on the other side to replace them. The reason of the phenomenon is this. The air constituting the wind from the south-east having passed over a vast extent of the southern ocean, comes charged with as much invisible moisture as its temperature can sustain. In rising up the side of the mountain it is rising in the atmosphere, and is thereby gradually escaping from a part of the pressure lately borne; and on attaining the summit it has dilated so much, and has consequently become so much colder, that it lets go part of its moisture. This then appears as the cloud just described; but it no sooner falls over the brow of the mountain, and again descends in the atmosphere to where it is pressed, and condensed, and heated as before, than it is re-dissolved and disappears:—the magnificent apparition dwelling only on the mountain top.

The foregoing reasoning explains why, along the sides of mountain ridges, clouds are generally seen floating at a certain height only, and therefore in strata nearly horizontal. The water is separated from the air at a certain temperature, which corresponds with the height, and above that height the air is at the time too dry and rare to have clouds. Very lofty summits are seen from a distance projecting much above the clouds, and the admirer of such scenery who climbs towards them, may have to contemplate the grand phenomena of the thunderstorm far beneath his feet. Teneriffe soars so sublimely, that the distant sailor not unfrequently mistakes the line of clouds hanging around its sides for the white streak which elsewhere indicates the cliffs and waves of the sea-shore.

651. When the elevation to which moist air is suddenly carried is very great, the fall of temperature is proportional, and the separating water becomes snow instead of rain. This phenomenon is remarkably illustrated by a great *Hero's* fountain, established in one of the salt mines of Hungary; during the play of which, the confined air in one place is so compressed, that on being suddenly released, it expands and cools enough to cause the moisture contained in it, to come out, even in summer, as a shower of snow.

Glaciers and Icebergs.

652. We may here consider the striking phenomenon of what are called glaciers, formed among mountains which rise above the snow-level of the region. When snow, falling on these mountains, as it does, through both summer and winter, accumulates on their sides beyond a certain degree, it breaks loose and slides down in masses called *avalanches* into the hollows and valleys below, and there, owing to the great pressure and partial meltings, it soon becomes solid ice, called a glacier, often hundreds of feet in thickness or depth. One of the singular facts connected with these masses is, that they have a slow onward motion toward the lower country, as if they were of semi-fluid or viscous substance, like soft pitch or yielding clay. It had been noted by the inhabitants around that huge pieces of rock, fallen from bordering heights to the surface of the ice, seemed to have a gradual onward motion towards the lower country, but only of late have scientific men ascertained that the whole mass of the glacier has such motion, carrying the rocky fragments on its surface. Then experiment shows that if a block of ice is crushed and broken by great pressure, and the pressure is continued afterwards, the fragments all perfectly re-unite to become as solid a mass as before, and in any new form which the resisting sides of the containing space may give. Now glacier-ice in a sloping valley is undergoing, by the pressure of its weight, a constant bruising and general internal fracture of its substance as it is forced along in its irregular channel, and the displaced parts are being as constantly re-united into a solid mass. Glaciers from smaller valleys meet and join with those in the larger, just as smaller streams of water meet to form large rivers. It is interesting to observe, that the constantly falling fragments of rock and earth from the elevations around the moving glacier, form continuous lines on the surface along the margins to the termination of the glacier, where the increasing warmth of the low country is causing the glacier-ice to melt and disappear; and the earthy loads there deposited form ridges or embankments, called *moraines*, of vast magnitude, crossing the mouth of the valley, the stupendous gatherings of bygone ages. The continual and rapid waste of glaciers going on below the level of the snow-line confines those of temperate regions to high positions among the mountains, but in colder regions towards the poles, glaciers extend down not merely to the sea-shores, but often project far into the sea. When such projections break off, they become the so-called icebergs met floating away from the places of their origin.

653. *Icebergs.*—Some remarks have already been made on these enormous masses of floating ice (see note, p. 409). Those met with in the North Atlantic are supposed to be derived from the great glaciers or ice deposits in the rocks on the coasts of Greenland, Spitzbergen, and other Arctic localities. Floating southwards towards the Mid-Atlantic, they make their presence known by cooling the temperature of the air and the sea-water for a considerable distance around them. Their proximity may in general be discovered by the thermometer, the sea-water indicating a much lower temperature than usual.

Owing to the specific gravity of ice being less than that of sea-water, about $\frac{1}{12}$th of the bulk of the ice is above, and $\frac{11}{12}$ths are below the sea-level. Ice-fields are icebergs of low altitude. An officer of the *Alexandra* measured one which had an average height of 51 feet, and a length and breadth of about two miles each way. A floe signifies a detached portion of one of these fields. Pack-ice means a number of floes so closely wedged together as to prevent the passage of a ship; and drift-ice implies that the floes are not welded together.

654. Although the proofs are not at once apparent, the line of congelation exists as truly everywhere in the open sky, over sea and plains, as where there are mountain heights to wear its livery; and considerably below the line, the cold, aided probably by electrical agency, is sufficient to produce, in the form of mist or clouds, a copious separation from the air of the watery vapour contained in it. There is thus in nature an admirable system at work to shade the surface of the earth at times from the too powerful rays of the sun, and to supply rain as wanted, without the transparency of the inferior regions of the atmosphere being much affected. As the watery evaporation rising from sea and lake, and invisibly diffused in the atmosphere, can reach only to the height where the cold is intense enough to condense it, the clouds may in general be regarded as the high stratum of that atmosphere of watery vapour or aëriform water, which is always mixed more or less with the atmosphere of mere air; and as the quantity of watery vapour which can exist invisibly in a given space depends altogether on the amount of heat present, the clouds in a cold or a humid atmosphere will generally be low, and in a warm or a dry atmosphere will be high, or there may be none. An aëronaut mounting in his balloon through a clear sky often enters a dense cloudy stratum, and for a time is surrounded by the gloom almost of night, the face of the earth below being completely hidden from him, while the heavenly bodies are equally veiled from him above; but rising still higher, he again emerges to brightness, and looks down upon the fleecy ocean rolling beneath, as a climber to a very lofty peak looks down from the pure atmosphere around it on the inferior region of clouds and storms.

655. The diminished temperature of air in the higher regions of the atmosphere often enables the natives of temperate climates, when obliged to reside in hot countries inimical to their health, to find near at hand, on some mountain height, the congenial temperature of their wished-for homes. The interiors of many tropical lands have localities of great extent, high table-lands which combine, as above described, the advantages of tropical situation and temperate climate, and which might well be inhabited by European colonists. Much of the central land of South America, is similarly circumstanced (Art. 639). It is not uncommon, where the ascent to such land is rapid, to find near the bottom, towns with their markets stored only with the productions of the equator, while higher up are seen also what belong to the temperate skies of Europe. In the province of Valencia, in Spain, invalids needing temperate climate can find it near the sea-level during winter, and in summer can climb the hills to enjoy the cool atmosphere which befits them.

656. The facts detailed in the preceding paragraphs illustrate the subject of the relation of *volume* in a body to the capacity for heat, by the change of capacity produced in the same quantity of air according as it is more or less either dilated or compressed. We have now to speak of the effect of permanent *density* in the same respect.

It might be anticipated that a dense body, or one in which the constituent particles may be supposed to fill more completely the space occupied by it than the particles of a rarer body, would have a smaller capacity for heat, in proportion to the smaller space left vacant in its mass; and in a general comparison of the capacities of *equal bulks* of different substances, such anticipation is partly verified. The relation, however, is by no means universal, nor at all in proportion to the differences of density, for water, which is denser than oil, has twice as much capacity for heat.

657. The relation, then, between various substances and heat, which we call capacity for heat, depends much more on the nature of the ultimate particles of the substances than either on the absolute bulk or comparative density of the masses. It has been ascertained that all material substances are composed of extremely minute unchangeable atoms, of which, in the different substances, the comparative weights have been determined (Art. 42), although not the absolute weights; that is to say, for example, the atom of gold is known to weigh nearly six times as much as the atom of iron, although we do not know how many thousands or millions of atoms are required to form a grain of either. And recent researches prove that the capacities for heat, or the specific heats of simple bodies, are inversely as their atomic weights, the two numbers multiplied together, therefore, being a constant quantity.

Instead of the term *capacity for heat* used in the preceding pages, with respect to particular substances, that of *specific heat* has by some authors been preferred; but as the latter gives to a commencing student, the idea rather of *kinds* of heat than of *quantities*, the term capacity has been here retained.

> "*Each substance in nature, for a given change of temperature, undergoes expansion in a degree proper to itself, the expansion generally increasing more rapidly than temperature, being remarkably greater therefore in liquids than in solids, and in gases than in liquids, the rate being quickened, moreover, near the points of change.*"

658. The following table, containing the names of some common substances, solid, liquid, and aëriform, shows approximately, by the figures following each, how much the substance increases in bulk by having its temperature raised from that of freezing to that of boiling water. A lump of glass, for instance, would gain one cubic inch for every 416 cubic inches contained in it; while a mass of water would gain one inch for twenty-one, dilating thus for the same range of temperature eighteen times more than the glass.

SOLIDS.

Flint-glass gains one part in	416
Deal	416
Steel	309
Iron	282
Copper	194
Brass	179
Silver	175
Tin	172
Lead	117
Zinc	113

LIQUIDS.

Mercury gains one part in	55
Water	21
Fixed oils	12
Alcohol	9

GASES

Common air, and all gases and vapours gain one part in about	3

659. We have to warn readers here not to confound the increase by heat of the general *bulk* of a solid body with the increase of its *length*. The latter is only one-third as great as the former. This will be understood by considering that the increase of bulk is made up of increase in the *length*, *breadth*, and *depth* (or *thickness*). If the substance of a metallic square rod or wire be dilated, by heat, a one-hundredth part of its bulk, it does not gain all that hundredth at its end, becoming 101 inches long instead of 100; but every part becomes deeper and broader in the same proportion as it becomes longer, and the rod gains in length only the third part of an inch. A fluid enclosed in a tube unchangeable by heat (if such tube there were) would show its whole dilatation in an increase of length, because there could be no swelling laterally, and its extremity, therefore, from any variation of temperature, would have a triple extent of motion. A linear dilatation of this kind is practically obtained in our mercurial thermometers, because the containing glass, although dilatable by heat, is much less dilatable than the fluid within it. As regards solids, we have to inquire so much more frequently respecting the dilatation in length, breadth, or thickness, that is to say, the *linear dilatation* in one direction, than respecting the increase of general bulk, that tables are commonly made stating only the linear dilatation. And this may be found at once from the above table by recollecting that it is one-third of the increase of bulk. Thus as glass, in passing from the freezing to the boiling heat of water, dilates one part in 416 of its bulk, it will dilate only one-third as much in length, namely one-1248th part.*

The expansion of solids by heat has been ascertained by bringing microscopic instruments to bear on marked rods of the different substances heated to various degrees in some liquid. Ramsden invented an instrument which, by a micrometer, would measure the rate of linear expansion on a solid up to the 70,000th of an inch. Whitworth's measuring machine serves to indicate a still smaller amount of expansion by heat, *i.e.*, up to the millionth part of an inch. The expansion of fluids, again, is found by filling a glass vessel with a known weight of a fluid, and then ascertaining how much is caused to run over or escape by a given increase of heat, or how much the fluid rises, when heated, into a long tubular neck like the stalk of a thermometer. This quantity, when the required allowance is made for the expansion of the heated glass vessel (already known), determines the increase in the fluid itself.

The general and comparative expansion of solids by heat are exemplified in the following facts:—

660. An iron bullet, when heated, cannot be made to enter an opening through which, when cold, it passes readily.

A leaden bullet, cast in a mould, occupies a greater space in the liquid than in the solid state. As it solidifies on the outside first, this leads to the curious results that in all cast bullets of any size there is a small vacuous space of the size of a barleycorn. This is easily observed by cutting the bullet through its axis. It is not formed in the centre of the sphere, but usually nearer to the surface. The vacuum thus left in the conversion of the liquids into the solid affects the centre of gravity of the bullet, and causes it to deviate from the line in which it is discharged. Owing to this defect bullets are made in the Royal Arsenal by compression, instead of by casting. In this case the bullet assumes the form of a solid sphere.

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* Glass without lead expands in length $\frac{1}{1142}$nd part, and platinum very little less, $\frac{1}{1187}$th. As they contract in these proportions glass may be fused to platinum by heat and they will cohere. All other metals, by reason of their great inequality in linear expansion, separate from glass on cooling.

A glass stopper sticking in the neck of a bottle may often be released by surrounding the neck with a cloth taken out of warm water, or by immersing the bottle in the water up to the neck, or by applying rapidly to the neck the flame of a spirit-lamp. By any one of these methods, the binding-ring of the neck is heated and expanded sooner than the stopper, and so becomes for a short time somewhat more loose upon it. Tapping gently at the same time on the stopper with a piece of wood favours the operation.

Pipes of cast-iron for conveying hot water, steam, hot air, or coal-gas, if of considerable length, must have joinings which allow a certain degree of shortening and lengthening, otherwise a change of temperature may destroy them. An incompetent person who undertook to warm a large manufactory by steam from one boiler, laid a rigid main pipe along a passage, with lateral branches passing tightly through holes into the several apartments. On his first admitting the steam, the expansion of the main pipe made many fractures at the branches.

An iron gate which, during a cold day, may be loose and easily shut or opened, on a warm day may stick, owing to there being greater expansion of it and of the neighbouring railing, than of the earth on which they are placed. The iron bars of railways are now formed with oblique surfaces at their meeting ends, to allow of expansion with changes of weather. The lid of a kettle, which can easily be raised when the water is cold, becomes fixed when the water is boiling.

Iron hoops fitted to barrels when hot, contract on cooling, and this contraction has the effect of binding the staves closer together. So the iron tires of wheels when put on in a heated state, contract on cooling and bind together more firmly the fellies and spokes of the wheels.

The iron pillars commonly used to support the front walls of houses of which the ground floors are intended to serve as shops, lift up the wall which rests upon them in warm weather, and in cold weather allow it again to subside.

The iron bridge which crosses the Thames between London and

Southwark, is raised in summer to a higher level than it has in winter. In some vast structures of this kind compensation must be made for these effects of expansion by heat. In the Menai Bridge suspension rollers have been introduced in order to allow of free expansion and contraction. The diurnal effect of heat upon the vast mass of metal in this bridge, is sensible and admits of measurement. Even when the sun is not visible, owing to dense fog or clouds, the position of this luminary is indicated by the greater expansile effect of the direct rays of heat on the metal.

When the stones of a building are held together by clamps or bars of iron driven into them, the expansion of these clamps in summer will force the stones apart sufficiently for dust or sandy particles to lodge between them : and then, on the return of winter, the stones, not being at liberty to close as before, will cause the ends of the shortened clamps to be drawn out, and the effect increasing with every succeeding year, the structure may at last be dangerously loosened.

661. The expansion of solids by heat, or their contraction on the withdrawal of it, is attended with considerable force. It is equal to that which would be required to elongate or condense the material to the same extent by mechanical means. According to Barlow a bar of malleable iron a square inch in section is stretched $\frac{1}{10000}$th of its length by a ton weight. A similar elongation is produced by a rise of 16° F. In this climate there is often a variation of 80° between the cold of winter and the heat of summer. A wrought-iron bar, ten inches long, will vary $\frac{1}{200}$th of an inch, and, if its two ends be securely fastened, will exert a strain equal to fifty tons on the square inch (Miller). These facts are of the greatest importance in the construction of buildings or bridges with iron pillars and girders.

The pitch of a pianoforte or harp is lowered on a warm day or in a warm room, owing to the expansion of the strings being greater than that of the wooden frame-work ; and on a cold day, the reverse will happen. Thus an instrument, which has been well tuned in a morning drawing-room, may make discords when the crowded evening party has heated the room.

Bell wires too slack in summer, may be of the proper length in winter.

A difference of the 100th of an inch in the length of a common pendulum causes a clock to err about ten seconds in twenty-four hours, and a rise or fall of 25° of Fahrenheit's thermometer may produce this difference. In order to counteract this expansion and increase of length in the pendulum rod, a glass vessel containing mercury is substituted for the solid ball or weight. As the rod expands downwards so the liquid mercury expands upwards, and the centre of gravity is therefore raised just enough to compensate for the lengthening of the pendulum rod.

Thin strips of two metals differently expansible by heat, may be soldered together throughout their length to form one long straight riband. If this be then heated or cooled, it bends or curls like damp paper held before a fire. A very sensitive thermometer has been constructed on this principle by Breguet.

662. As a rule all solids expand equally in their three dimensions, but owing to the force of cohesion in some crystalline solids being stronger in one direction or axis than in another, the effect of heat upon them is to expand them unequally. When a rhombic crystal of Iceland spar was heated from 32° to 212°, Mitscherlich observed that it was so elongated as to render the obtuse angles more acute. There was a difference of 8½ degrees in the inclination of the surfaces of the crystal.

Crystals when heated, do not expand quite equally in breadth and in length. The same is true of fibrous substances, as wood, which expands and contracts more in breadth than in length, hence wood is well fitted for the pendulum rods of astronomical clocks. This is also instanced in the leaking, during cold weather, of a ship's deck, which in warm weather is tight.

Bodies expanded by heat, unless when their intimate structure is changed by it, regain exactly their former dimensions on being cooled. Heat produces no permanent change in them. They weigh the same before and after.

As is seen in the preceding table (p. 454), the expansion of liquids by heat is much greater than of solids.

663. In a general way it may be stated that the same quantity of heat which would expand a solid $\frac{1}{1000}$th part would expand a liquid $\frac{1}{10}$th and a gas $\frac{1}{3}$rd of its volume. In reference to gases, Regnault found that 1000 parts of atmospheric air in being heated from 32° to 212° became 1367 parts. All gases and vapours expand in about equal proportions between these temperatures, and this may be taken at $\frac{11}{30}$ of their volume at 32°. This is equivalent to $\frac{1}{490}$ of the volume at 32° for each degree of Fahrenheit between 32° and 212°, so that when heated 490°, air, or any gas or vapour at the temperature of 32°, would be doubled in volume. The expansion of gases differs remarkably from that of liquids and solids in these respects: 1. It takes place equally for equal increments of heat, and thus an *air-thermometer* within a certain range, serves to measure degrees of temperature more accurately. 2. All gases, in spite of their great difference of density, expand equally for equal additions of heat. Thus carbonic acid and hydrogen expand in an equal ratio between 32° and 600°, although carbonic acid is 22 times heavier than hydrogen.

664. *Expansion of Liquids.*—The lighter the liquid and the lower its boiling point, the more it expands by heat. Thus alcohol at the same temperature increases in volume more than water, and ether more than alcohol. By the addition of 180°, alcohol is observed to expand $\frac{1}{9}$th of its bulk, water $\frac{1}{21}$st, and mercury $\frac{1}{55}$th. Owing to this alteration in volume, hot water is lighter than cold, and when coloured with archil, it may be made to float visibly on cold water.

Of all liquids there is none which undergoes such remarkable changes in bulk by the addition or withdrawal of heat, as water. A cubic inch of water in passing to the solid state forms rather more than a cubic inch of ice, and a cubic inch of water, heated to 212° degrees, is converted into 2000 cubic inches of aqueous vapour or steam.

A cask quite filled with liquid in winter, must in summer force its plug or burst: and a vessel which has been filled to the lip with warm liquid, will not be full when the liquid has cooled. If a tea-kettle be quite full when placed on the fire, it overflows when heated to the boiling point. It is thus that the mercury rises and falls in the stalk of a thermometer, in proportion as that contained in the bulb is heated or cooled.

665. There exists, however, in the case of water, a singular exception, already mentioned, to the law of expansion by heat and contraction by cold, producing certain beneficial results in nature. Water contracts only down to the temperature of 40°, while, from that to 32°, which is its freezing point, it again dilates or expands. Water is the only liquid which is known to possess this remarkable property.* If we apply heat to a quantity of water at 39°

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* Some melted metals and alloys expand on passing from the liquid to the solid state. This property is observed in bismuth, in fusible metal, in type metal, and cast iron, especially that variety of iron which contains phosphorus. It is owing to this expansion in cooling that such exquisitely fine castings of iron are obtained, as may be seen in the Berlin iron ornaments. For a similar reason type metal takes the sharpest impression in stereotype castings.

it will go on increasing in volume up to 47°; if we cool the water from 39° to 32° it goes on expanding in equal proportion until it freezes. Water at 47° and 32° are therefore equal in bulk. This curious fact may be illustrated by the following experiment:—Place glass bulbs provided with stalks containing water and mercury, and graduated from 32° to 50°, in basins in which ice is melting. The mercury will sink down to 32° and there remain steadily. The water will sink until it reaches 39° (or more correctly 39½°); but it will then begin to rise, although still undergoing the cooling process. When just about to freeze, *i.e.*, at 32°, the water will have expanded so as to mark 47°. Thus, whether cooled 7° below 39° or heated 7° above it, it will occupy the same volume. Hence it appears that there is an expansion of water by *cold* as well as by *heat*, a fact for which no theory of heat has yet satisfactorily accounted.

The temperature of maximum density (39°) applies only to fresh water. If it contains much saline matter, the degree for maximum density is much lowered. Thus sea water continues to decrease in bulk down to its freezing point, which is about 27° if the water is agitated, and 25° degrees if still. It is just before it freezes that salt water has its greatest density. This is indicated by the specific gravity imparted by the salt, and not by temperature. This will explain why in the soundings taken in the deep sea the temperature of the bottom stratum is not invariably found at 39½° or 40°.

666. *Expansion of Gases.*—Gases are expanded by heat still more than liquids. A difference of one degree causes a perceptible difference in volume, and allowance must be made for this in the measurement of a gas. Heated air weighs less than cold air, a fact which may be thus demonstrated:—Balance two cones of paper with the wide open ends downwards at the end of a scale beam. The cones may be easily made of cartridge paper cut to shape and gummed. The temperature of the air is the same in the two cones, and they will be exactly equal in weight. If a lighted wax taper is now introduced under one of the cones the air in it is expanded, a portion is forced out, and the cone now rises. By transferring the taper to the other cone, the air in that may be rendered lighter—the experiment being performed alternately with each cone, allowing sufficient time for cooling.* The ascent of the Montgolfier or fire-balloon is based entirely on this principle.

The extent of this dilatation in gases is so much greater than in liquids or solids, that it forces itself much more strikingly upon the attention. Thus a bladder containing a small quantity of air and secured by a stop-cock, becomes apparently filled and quite tense on being held to the fire. The air in a balloon just escaping from a cloud, has been so suddenly expanded by the direct rays of the sun, as to injure the texture of the balloon. Some of the fatal accidents among aëronauts have been owing to this occurrence.

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* A balanced thin glass shade may be substituted for the paper cones with a similar result.

In consequence of this great increase of volume by heat, hot air readily floats on cold, a point of considerable importance in reference to warming and ventilation. During cold weather thermometers placed on the floor and the ceiling of an apartment heated by an open grate, will indicate very different degrees of temperature. In the opening of a door the flame of a candle will be carried outwards at the top by the warm air rushing out of the room, while on the floor, it will be blown inwards by the current of cold air flowing in.

The expansion of gaseous or aëriform bodies by heat produces many important effects in nature. Some of these have already been considered in preceding parts of this work, as, the rising of heated air in the atmosphere causing the winds all over the earth; the same in our fires and chimneys supporting combustion, and ventilating and purifying our houses; the same again from around animal bodies, removing the poisonous or contaminated air which issues from the lungs, and insuring a constant supply of fresh air for the support of life.

The expansion of air and other gaseous matter by heat has lately become a subject of very high interest, from having led to new views as to the nature not only of heat, but of force or energy in general. This subject will be considered in another place.

> "*The expansion of bodies by heat increases more rapidly than the temperature, and particularly near the melting and boiling points, that is, their points of changing into liquid or gas.*"

667. If a certain increase of temperature, accurately measured by any of the methods now practised, be given to a mass of cold water, it will produce in that a certain increment of bulk: and if other equal additions be afterwards successively made, each will produce a rather greater increment of bulk than the preceding, with diminished specific gravity, particularly when the water approaches to boiling. Thus, 90° added to water at 32° produces a certain expansion or increase of volume amounting to 4·7 in raising it to 122°. When, however, 90° are added to the liquid already at a temperature of 122°, so as to raise it to 212°, the rate of expansion is 15, or nearly threefold that which was produced by the same number of degrees at the lower temperature. It is this inequality which renders water wholly unfitted for the purposes of a thermometer. It is found that after the water has been converted into steam, or become aëriform, any farther increase of bulk is always closely proportioned to the increase of temperature. What is thus true of water in relation to heat is true of bodies generally, each, however, having a rate of expansion and temperatures for melting and boiling proper to itself. The quickened rate of expansion in solids and liquids might have been anticipated, from reflecting that each successive quantity of heat added to a liquid, meets with less resistance to its expanding power than the preceding quantity, owing to the diminishing force of the mutual attraction of the particles as they separate from each other ; while in a gas, as such cohesion has altogether ceased, each addition of heat is at liberty to produce its full effect. If the capacity of substances for heat did not increase with their bulk, the terms "increase in the amount of heat" and "increase of temperature" would have the same meaning, and this subject would be more simple.

668. The reflection may naturally occur here, that, as in the common thermometer, the mercury must rise or expand more for a given quantity of heat added at a high than at a low temperature, the scale should be so divided as to correspond with the inequality. This reasoning is good, but the difficulty of complying with it in practice is such, that the inconvenience of the slight error arising from an equal division is commonly submitted to. An air-thermometer having equal divisions is more nearly correct, but from wanting many of the advantages of the mercurial thermometer is little employed. The subject of unequal thermometric dilatation in the same liquid, and of the differences in that respect in different liquids, depending on the proximity to their boiling points, was well illustrated by De Luc's experiment of charging with different liquids, thermometer-tubes divided according to the scale of Reaumur, and, while they were being heated through the same range of temperature, from his zero (0°) or freezing point to boiling 80°), noting their comparative indications. The discordance of the dilatations in different tubes when the instruments were placed together and heated from the freezing (marked 0°, or zero, on

Reaumur's scale) to the boiling degree of water (marked 80°), was as here detailed—

Mercury.	Alcohol.	Water.
0	0	0
10	7·9	0·2
20	16·5	4·1
30	25·6	11·2
40	35·1	20·5
50	45·3	32
60	56·8	45·8
70	67·8	62
80	80	80

The singular discrepancy in the case of water is owing to the peculiarity, described in Art. 665, of its contracting by cold only down to about 40° of Fahrenheit, and then again dilating until it freezes.

> "*To melt a solid body, or to vaporize a liquid, a large addition of heat enters into it, but in the new arrangement of the particles and the generally increased volume of the mass, the heat becomes hidden from the thermometer and is called* LATENT HEAT. *It may be made to re-appear during the converse changes, after any interval whatever.*"

669. The expansion of bodies by heat, instead of proceeding throughout in a nearly uniform or gradual manner, makes in its course two great leaps, with singular transformations of the body: the first, when the solid breaks down into a liquid; the second, when the liquid expands into a gas; so that there are in all three very distinct modifications or stages of existence for the body, dependent on the agency of heat. Water, for instance, when at a low temperature, exists in the solid form called *ice;* but at 32° of Fahrenheit, on receiving more heat, it gradually becomes liquid or *water;* and on receiving still more heat it acquires at 212°, even under the resisting pressure of the atmosphere, a bulk nearly 2000 times greater than it had as a liquid (gradually as regards the whole, but suddenly as regards each separate portion), being then called *steam*, or aëriform water, or aqueous vapour. Other bodies under analogous circumstances undergo similar changes. It is further remarkable, that although during the changes a large quantity of heat enters the mass, producing in the one case liquidity, in the other the form of gas or vapour, the temperature or indication of the thermometer is the same, immediately after, as immediately before the change, the heat received in the interval becoming hidden or latent in the mass :—thus water running from melting ice affects the thermometer just as the ice does, and steam over boiling water appears no hotter than the water. The glory of originally discovering the facts, to recall which the terms *latent heat* are used, belongs to the illustrious Dr. Black. No discovery in reference to heat has proved of greater importance to mankind than this. The modern steam-engine was an early result of this discovery and of kindred investigations made by his friend, James Watt.

670. We may select the following instances as serving to display the subject of *latent heat* in its various bearings.

A mass of ice brought into a warm room, and there receiving heat from every object around it, will soon reach the temperature of melting or 32°, but afterwards both the ice and the water formed from it will continue at that temperature until all be melted. The heat which continues to enter the solid effects a change only in the form, not in the temperature of the mass. The temperature of the liquid is not raised in the smallest degree. It remains at 32° until all the ice is melted. By this invariable result one may test the accuracy of a thermometer. Whatever time may have been required for heating the mass of ice *one degree*, just one hundred and forty times as much will be required for melting it; proving that 140° is the latent heat of water.

If two similar flasks, one filled with ice at 32°, and the other with water at 32°, be placed in the same oven or over like flames, the water will gain 140 degrees of heat, while the ice is merely being melted into water at 32° : and in the course of the experiment, a correspondence will always exist between the phenomena; for instance, when the water has gained 14° of heat, it will be found that just a tenth part of the ice is melted.

If equal quantities of hot and cold water be mixed together, the whole acquires a middle temperature, each degree lost by the hot water becoming a degree gained by the cold. Thus, on mixing equal measures of water at 70° and 130°, the mixture will have the mean temperature of 100°, the hot water loses 30°, and the cooler water gains 30°. Hence it follows that if equal weights of water at 32° and 172° respectively are mixed, the temperature of the mixture will be 102°. But if ice at 32° be mixed with an equal weight of water at 172°, the mixture when the ice has melted will have only a temperature of 32°. Thus, in the substitution of ice for ice-cold water there is an actual loss of heat to the amount of 140°. This expresses the latent heat of water at 32° compared with that of ice at the same temperature, and it follows that on re-converting the water into ice the amount of heat which was latent in the water (*i.e.*, not appreciable to the thermometer) must be again set free. Hence, during a thaw the temperature of the air near the surface of the earth is much lowered; while, on the other hand, in the act of freezing, water, whether in the form of snow or ice, gives out a large amount of heat, which renders the temperature of the air milder.

If a flask of water at 32° or its freezing point, and a similar flask of strong brine (which does not freeze until much colder) also at 32°, be exposed together in the same cold place, it will be found that when the brine has lost 10° of its heat, the water-flask will still exhibit an undiminished temperature, but a fourteenth part of its contents will be converted into ice. As in such a case, the water flask must continue to radiate heat just as much as the other, it can maintain its temperature only by absorbing into its general mass the heat which was latent in the portion of water frozen.

671. It has been elsewhere stated that by slowly cooling water which is kept in perfect repose, its temperature, while it is yet liquid; may be lowered to ten degrees or even more below its ordinary freezing point; but then, on the slightest agitation, ice will be formed. It might be expected in such a case, that the whole water would instantly freeze, because all of it is colder than common ice; but in fact, only a fourteenth part freezes, and singularly, both that fourteenth and the remaining liquid are rendered in the moment ten degrees warmer—rising to 32°. Here the 140° of latent heat escaping from the fourteenth part of the water which freezes, become 10° of sensible heat for the whole mass, so that the remaining water has the temperature at which water in an open vessel begins to freeze.

Other liquids undergo similar changes. Glacial acetic acid may be cooled to below 40° without crystallizing, provided it be kept at rest; but if moved or shaken, the liquid is suddenly converted into a solid crystalline mass, and the temperature rises.

There are certain saline solutions which manifest this property in a remarkable degree. If two parts of crystallized sulphate of soda (Glauber's salt) are dissolved in one part of water by heat, and the solution is allowed to cool quietly in a flask not communicating with the atmosphere, none of the salt will be deposited. The contents of the flask will remain perfectly liquid until this has been agitated, or some foreign substance introduced into the liquid. A chip of wood or a grain of sand is sufficient for this purpose. The whole then sets into a crystalline solid. Heat, light, and electricity are evolved during this remarkable transformation. The evolution of heat is easily demonstrated by plunging the bulb of a spirit thermometer into the liquid: the crystallizing solid is then deposited on and around the bulb. The writer has found that from about eight ounces of liquid, thus solidified, the thermometer has risen eight degrees. He has also found that this phenomenon has equally taken place after keeping the solution for five years.*

When equal parts of diluted sulphuric acid and a strong solution of chloride of calcium are suddenly mixed, the two liquids are converted into a white solid (sulphate of lime) with the production of sensible heat. So, water thrown upon fresh burnt lime for the purpose of slaking it, is solidified in combination with the lime, and gives out its latent heat. Three parts of lime will thus completely solidify one part of water. The heat is such that phosphorus is rapidly melted and ignited. The temperature sometimes reaches 300°, and two parts of fresh lime to one of water will, under favourable conditions, produce a heat of 616°. Barges and carts laden with fresh lime and exposed to heavy rain, have been thus set on fire by the concentration and combination of the heat.

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* As this experiment has been generally performed by closely securing the neck of the flask with bladder while the liquid was still warm, so that a partial vacuum was produced on cooling, it was thought that the solidification depended on atmospheric pressure as a result of the readmission of air to the liquid. This, however, is not the true explanation. As the solution equally remains liquid in a Florence flask on covering the surface with a stratum of oil, which cannot prevent atmospheric pressure, it is clear that this is not the cause. It appears that the crystalline sulphate of soda in strong solution is rendered anhydrous at the boiling point, and so remains for any length of time dissolved in the liquid. A very slight movement of the particles of the liquid from vibration or from mechanical contact of any substance induces crystallization. The salt combines with so much water in crystallizing, that the whole of that in which it is dissolved, is barely sufficient to supply the proper proportion. It is this sudden solidification of the water, as in the slaking of lime, which causes the temperature to rise.

672. From the already-mentioned facts it will be perceived that the quantity of ice formed or melted in any case, becomes a correct measure of the quantity of heat transferred. On this principle the illustrious Lavoisier constructed his *calorimeter*, or heat-measurer. It is a metallic case or vessel charged with ice, and the quantity of heat given out by any body placed in it is indicated by the quantity of water collected from the melted ice.

Had the latent heat of water been only 1° or 2°, instead of 140°, the earth, except in its tropical regions, would have been scarcely habitable by man. The cold of a single night might have frozen to the bottom, the water of a deep lake, and the heat of a single day might have converted the accumulated snows of a winter, into one sudden and most destructive inundation. As the fact is, however, both changes are beautifully graduated, and thus these dangers are averted.

The presence of latent heat in other liquids than water, is familiarly exhibited in the *slow* melting of various substances, as of the metals, lead or pig-iron, for instance; of butter, or oils; of glass, &c.; and, on the other hand, in the slow solidification of any melted masses when heat is again withdrawn.

The substances below enumerated, while passing from the solid to the liquid state, absorb and render latent the quantities of heat here noted; which quantities are therefore called the latent heats of the liquids.

Water	140°	Zinc	493°
Mercury	142	Sulphur . . .	145
Bees'-wax . . .	175	Lead	162
Tin	500	Bismuth . . .	550

673. It is a fact to be mentioned here that alloys or mixed metals are fusible at lower temperatures than the metals separately. Common solders are examples. An alloy consisting of eight parts of bismuth, five of lead, and three of tin, melts when thrown into boiling water. It is a kindred fact that in smelting metallic ores in furnaces, the mixture with them of certain other fusible substances, such as carbonate of lime, or fluorspar, facilitates the fusion of the metal.*

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* It is to be observed that the ideas underlying the expression *latent heat* were originally based on the material doctrine of heat. *Caloric* was supposed to be the essence of which heat was somehow the exhibition, and when heat was rendered latent, or disappeared, it was the result of an

"*Latent heat of Steam and Gases.*"

674. Water in a vessel placed over a fire gradually attains the boiling temperature, or 212°, but afterwards its temperature rises no more, because the further addition of heat becomes *latent* in the steam escaping during the ebullition. One way of determining the quantity of heat which becomes latent in steam is to note how much more time is required for boiling a quantity of water to dryness, than for merely heating it to the boiling point. The experiment indicates nearly 1000 degrees; that is to say, nearly five and a half times as much heat becomes latent in any quantity of water formed into steam, as would raise the temperature of that quantity from freezing to boiling.

If we place in the same oven, or over similar flames, two like ves-

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absorption of caloric among the intermolecular pores of the body; the reappearance of this latent heat, on the body resuming its original condition, was simply the squeezing out, as it were, of the caloric which was stowed away in the molecular recesses of the body.

The modern doctrine of energy necessitates a different explanation of the phenomena of latent heat. Heat is a form of energy; and no destruction or annihilation of energy is possible. If it disappear from the active form, its equivalent must be found in some other form. When the mechanical energy exerted in raising a weight to a height appears at first sight to have been simply expended, dissipated, or destroyed, we find (see Section II.) that in reality the energy has been stored in a potential condition in the weight, and is ready at any moment to restore the original energy seemingly lost upon it. In like manner when heat-energy disappears in the conversion of a solid into a liquid, such as ice into water, we may look for its existence in some new form or condition. From the analogy of mechanical energy, we conclude that the separation of the molecules or particles of a body, which accompanies the impartation of heat, represents the potential equivalent of the actual heat-motion or energy which has become latent or disappeared. The force of cohesion has to be overcome in the expansion of a body, just as the force of gravity has to be overcome in separating a weight from the earth, and the force expended in giving this new position, exists in the potential condition of the parts, and may be recovered when the original attracting force is allowed to restore the original arrangement. Thus the latent heat of water is the potential heat-energy of the separated particles, which appears again as actual or sensible heat-energy on the collapse of these particles into the solid form of ice.

sels containing water, one of which is open at the top and the other is strongly closed, the two will gain heat equally up to the boiling point, but afterwards the open vessel, from giving out steam, will remain at the same temperature, while the other, by retaining all the heat which enters, will show the temperature continuing to rise, as before, until the increasing tendency of the water to dilate, forces the vessel open or bursts it. Supposing the water in the latter vessel, before vent is given, to have become 100° hotter than common boiling water, instead of the whole, when set at liberty, being immediately converted into steam, as might be expected, only about a tenth part will be so changed,—the same quantity as will be found to have already escaped from the other vessel—for the tenth part requiring in the form of steam 1000° of latent heat, will take the excess of 100° from the other nine parts, and will leave them in the state of common boiling water. If, however, water heated considerably beyond the boiling point be allowed to expand *very suddenly*, the whole is blown out of the vessel as a mist by the steam formed at the same instant through every part of the mass, but the whole mass in such a case is no more converted into steam, than the whole of a bottleful of very brisk *soda water* is converted into gas when similarly thrown out by the sudden extrication of the carbonic acid gas, on uncorking the bottle. Misconception of this matter has led to very wasteful experiments on steam engines of unusually high pressure. It has been said that the water in such cases is "flashed into steam."

The same indication as to the latent heat of steam, is obtained by the converse experiment of first converting a given quantity of water into steam, and then admitting it to cold water or to ice. A pound of steam so treated will raise the temperature of ten pounds of cold water 100 degrees, or will melt about seven pounds of ice.

In the great quantity of heat which becomes latent in steam, we perceive the reason why water projected upon a raging fire so powerfully represses it; and, again, why *fire* and *water* are so often associated proverbially as exemplifying a fierce antagonism.

675. *High boiling point.*—Although the boiling point of water is usually fixed at 212°, and the production of steam takes place gradually as the water is heated, yet these conditions are liable to variation. From the researches of Faraday, it would appear that the quiescent conditions above mentioned are owing to the presence of air in the water. He found that absolutely pure water deprived of air might be heated to 240° without boiling, and that it was then suddenly converted into vapour with explosive violence. A piece of pure ice free from air was heated in a vessel containing oil, and he found that when the water produced from the ice had reached a temperature of 240°, the whole was converted into vapour with explosion.

The water in the cryophorus, or water-hammer, contains no air, and, if heated, would be suddenly converted with explosion into steam at 240°, destroying the instrument.

676. *Spheroidal state.*—There is another remarkable condition of water with respect to heat which may be here noticed, namely, the spheroidal state. When water is poured in small quantities at a time, into a clean platinum or porcelain dish, heated to full redness (*i.e.*, above 1000°), it does not boil, and does not produce any visible vapour. The liquid assumes what is called the spheroidal state, and rolls about in a stratum which presents a convexity on all sides like a quantity of mercury in a watch-glass. The water does not appear to touch in any part the red-hot surface of the containing vessel. At this high temperature there appears to be a complete repulsion between the water and the vessel, owing probably to the presence of a layer of vapour between the two. This observation applies not only to water, but to all other liquids which are not too rapidly evaporated. Boutigny, who first pointed out this effect of heat on water, found that the liquid while in this state had a temperature a few degrees below its boiling point. The liquid continues in incessant motion, gradually diminishes in volume, and at last evaporates entirely, leaving only the solid matters which may have been contained in it. If, while the water is in this spheroidal state, the source of heat is suddenly withdrawn, the metal becomes cooled, and at a certain point the water comes in contact with the heated surface, and a large portion of it is suddenly converted into steam with explosive violence. Explosions of steam boilers have been occasionally traced to this cause, when water has been turned into an over-heated boiler. Water already warmed assumes this condition more readily than cold water.

All liquids and all solids which become liquefied by heat may assume a similar condition if the metallic surface be brought to a sufficiently high temperature. Solid iodine thus thrown on platinum melts, and becomes spheroidal, evolving a violet vapour. When the heat is turned off, and the metallic surface cooled, the melted iodine coming in contact with the metal, produces suddenly a copious cloud of dense vapour.

677. Substances differ among themselves in regard to the latent heat of their vapours as much as in their other relations to heat. Thus the latent heat of the vapour or steam of—

Water	is 972°
Alcohol	385
Ether	162
Oil of turpentine	133

From the less abundant latent heat in these last-mentioned vapours than in that of water, one might at first suppose that there would be a great advantage in using them for steam-engines. Accordingly, numerous experiments have been made, and patents secured, under this idea ; but the fact is, that in the same proportion as the latent heat is less, the elasticity of the vapour is less, and therefore no mechanical advantage is obtainable.

678. It has already been stated that many gases—or substances usually met with in the aëriform state—may be reduced to the liquid, or even solid form, by simple pressure, and abstraction of the heat which exists in them while in the aëriform state. Carbonic acid, and other gases, have been treated in this way. Some are liquefied by cooling only, and some by cooling conjoined with pressure. There are a few which resist both cooling and pressure. These are permanent gases ; oxygen, hydrogen, and nitrogen are the principal substances of this group. It also became an interesting question whether many of the substances commonly seen as liquids on the face of the earth, where they are bearing the pressure of the atmosphere, would have the form of liquid if that pressure did not exist.

On investigating this subject by experiment, we accordingly find, that *ether*, *alcohol*, *chloroform*, *naphtha*, *benzoline*, *volatile oils*, *&c.*, and even *water* itself, are known to us here as liquids only because their particles are kept together by the weight and pressure of a superincumbent atmosphere. Any of these substances, relieved by art from such pressure, quickly become vapours or gases, just as carbonic acid gas or any other which has been kept in the state of liquid by great pressure, becomes again a gas on the removal of the pressure.

679. In another page we have explained the dependence of the three forms which any body may assume, *viz.*, of solid, liquid, or gas, on the quantity of heat diffused among the particles : we now see, however, that in order to understand the subject completely, we must consider also the effect of accidental pressure; for while heat is the power separating the atoms in the changes mentioned, it has to overcome both the mutual attractions of the atoms and the additional force of the atmosphere pressing them together. The combined influence of these forces is fully displayed in the phenomena of *boiling* and *evaporation*, which exhibit the progress of the change of a liquid into an aëriform fluid. We now proceed to examine these phenomena.

680. *Boiling.*—If water be placed in a suitable vessel (it may be a glass flask) over a common fire, or over the flame of a lamp, it is gradually heated to a certain degree; and then small bubbles of aëriform matter, *viz.*, water, in the state called steam, are seen forming at the bottom of the vessel, and successively rising to the surface, where they disappear by mixing with the atmosphere; and the operation being continued, the quantity of water diminishes with every bubble, until the whole vanishes as aëriform water or steam.

This change takes place in water, under common circumstances, at the degree of heat marked 212° on Fahrenheit's thermometer, and called on that account the *boiling point* of water; at which degree, therefore, the repulsive power or agitation among the particles is just sufficient to overcome both their natural attraction and the compressing force of the atmosphere of fifteen pounds on the square inch. But a less degree of heat suffices if the pressure of the atmosphere be lessened or removed; and a greater degree is required if the pressure be increased. Water on the top of Mont Blanc boils at 180°, because relieved from the pressure of the air which is below the level of the mountain's summit; and at all intermediate heights in descending to the level of the sea, or beyond that into mines, there is a corresponding increase of the boiling temperature.

So exactly is this the case, that a good method of ascertaining the heights of different places, is found to be merely by observing the temperature of boiling water at them. To many persons the information here given, that boiling water is not equally hot in all places, will appear extraordinary: but they will now understand the reason, and, further, that even in the same place, at different times, when the barometer is higher or lower than usual, there will be corresponding differences. In the city of Mexico, which is on a table-land 7471 feet above the level of the sea, water boils at 199°. In Quito, at an elevation of 9341 feet, at 195°; on the summit of Mount Etna, at a height of 10,955 feet, at 192°; and on the summit of Mont Blanc, 15,630 feet, at 182°.

Again, near the bottom of a boiler, the water is hotter than above, because it is bearing an additional pressure, proportioned to the depth, and does not therefore take the form of steam so readily as it would if a little higher up. In very large and deep boilers, therefore, such as are used in great porter breweries, the boiling liquid is much more heated than it can be in smaller vessels;—a circumstance which probably has an influence on its ultimate quality.

In the close wrought-iron boilers employed for heating houses by the circulation of hot water, the boiling temperature is raised to 250° or 260° according to the columnar pressure of the water on the boiler. This depends on the height of the cistern from which the boiler is supplied. In locomotive engines close boilers under strong pressure are used. The boiling point is here often raised by the proper adjustment of safety valves to from 280° to 290°.

While water under common atmospheric pressure, or when the barometer stands at thirty inches, boils at 212°, other substances, with other relations to heat, have their *boiling points* higher or lower:—ether, for instance, boils at 96°; chloroform at 140°; spirit or alcohol at 174°; fish-oil and tallow at about 600°; mercury and oil of vitriol at 650°. This explains why a burn from boiling oil is so dreaded, and why flesh or fish boiled in water is so different from what is cooked by frying or otherwise in melted fat or in oil.

681. It is in consequence of the different temperatures at which the particles of different substances acquire repulsion enough to rise against the atmospheric resistance, that we are enabled to perform the operation called *distilling*. If any fermented fluid, for instance, containing alcoholic spirit and water, as wine or beer, be heated up to 180°, the spirit will pass off in the aëriform state, leaving the greater part of the water behind, and it may be cooled to a liquid by condensation in any fit receiver. Distillation is the only means we possess of separating many substances from each other: as spirit from wine or any other fermented liquor; various acids from water; pure water itself from the salt of sea-water or other impurity;—and even the separation of mercury from silver or gold which it has been employed to dissolve from among the rubbish of a mine or river-bottom, is merely a distillation which saves the mercury to be used again.

682. We must recall to mind here what has been mentioned in another part of the work (Art. 669), that a large amount of heat enters into every substance during the change of form from solid to liquid, or from liquid to vapour;—which quantity, from not remaining sensible to the thermometer, has received the name of *latent* or *concealed heat.* The whole of this is given out again in the contrary change. In the conversion of water into steam, the heat which thus disappears is about 1000 degrees, or six times as much as is required to raise the cold water to the boiling point: this is proved by the time and fuel expended in boiling any quantity to dryness, and by the fact that a pint of water in the form of steam will combine instantly with six pints of cold water, raising the whole to boiling heat.

But for the fact of latent heat, the conversion of a liquid into an aëriform or gaseous mass would not be the gradual process of boiling which we now see, but a sudden and terrible explosion: for when any quantity of water is raised to the boiling heat, one degree of heat additional would be sufficient to convert the whole into steam. For a similar reason, the thawing of winter snow would always lead to a sudden and frightful inundation; the whole load on a mountain or plain becoming at once converted into a lake bursting from its enclosing barriers. On the other hand, if water in freezing had not to give out gradually its latent heat, after any quantity were once cooled down to the freezing point, the abstraction from it of one degree more would instantly convert the whole into a solid mass. Thus, then, by admirable arrangement effecting most important purposes in nature and art, all changes from solid to liquid and from liquid to vapour, and the reverse changes, are very gradual.

If a little heat be abstracted from steam, a small part of the steam proportioned to the abstraction is immediately condensed into water. What is called steam in common language—as the vapour which becomes visible at a little distance from the spout of a boiling kettle or the top of a tea urn—is not truly *steam*, but small globules of water already condensed by the cold air and mixed with it.* True steam is as dry and invisible as air itself; but the instant that it comes in contact with air or other bodies colder than itself, the cooled part becomes water. A similar phenomenon is seen when a person directs his warm breath (which has always some vapour of water invisibly mixed with it) against a window-pane or looking-glass, or any polished metallic surface, colder than the breath ; a cloud or dimness immediately covers the surface, because the water of the breath is condensed upon it. Light traversing this film of vapour condensed on the glass is refracted and split into circles of prismatic colours.

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* These minute globules of water condensed from steam have a spherical form. They decompose light into the prismatic colours. If the condensed vapour is examined as it rises from any metallic surface, as from a teaspoon dipped into hot water, the light of a candle or lamp traversing the globules of steam, will be resolved into the colours of the spectrum. The light is decomposed by diffraction in traversing these globules of condensed vapour

683. In order to exhibit the effect of diminished pressure, water several degrees below the boiling point of low situations, but which would be boiling at the top of Mont Blanc, is caused to boil instantly by placing it under the receiver of an air-pump, and making a few strokes of the piston. Water may be thus made to boil at 70°. If the exhaustion be rendered nearly complete, the water will rise, even when colder than the blood of animals ; and at degrees of temperature still much lower, it will at the surface be assuming the form of air, although not with a force sufficient to produce the visible agitation of boiling. The following experiment will show the boiling of water under diminished pressure in the absence of an air-pump. Boil water in a clean Florence oil-flask half full, until all the air has been expelled from the flask. Remove the flask and immediately close the mouth of it with a very accurately fitting cork. This should be so well fitted that no water can escape on inverting the flask. Place it inverted on a ring-stand, and now pour over it carefully some cold water. The steam in the body of the flask is immediately condensed—the pressure on the water is thereby diminished, and the water begins again to boil —the boiling continuing for some time.* Other liquids, as alcohol, ether, &c., from requiring inferior degrees of heat to separate their particles to aëriform distances, boil under the receiver of an air-pump at very low temperatures; ether, for instance, when as cold as freezing water. As a rule liquids boil *in vacuo* from 60° to 140° below their ordinary boiling points.

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* The following is a still more remarkable experiment, as it illustrates the force of atmospheric pressure when aqueous vapour enclosed thus undergoes sudden condensation. Place a thin stratum of water in a large cylinder made of the thinnest tin plate well-soldered, and having only a screw stop-cock at the top for pouring in the water and shutting off the steam. Open the stop-cock and boil the water by applying heat to the bottom of the cylinder. After boiling for some time, all the air is expelled by the escaping steam. When this has occured, withdraw the tin vessel from the fire, closing the stop-cock at the same time. In a few minutes, as a result of spontaneous cooling or by pouring over the vessel cold water, the steam is condensed in the interior, and the vessel is crumpled up by atmospheric pressure as if it were a scroll of paper.

On the other hand, in order to exhibit the effect of increased pressure, if we confine the particles of a liquid still more than by a common atmospheric or equivalent pressure, degrees of heat higher than the common boiling point will be required to separate them. In a diving bell, or in a deep mine, like that of Monkwearmouth, near Sunderland, the boiling point of water is higher than 212° in proportion to the depth reached: and if, at the surface of the earth, we heat water in a close vessel into which air is forced, so as to press thirty pounds on the inch instead of fifteen, as the atmosphere does, or from which we prevent the steam's escaping until it has acquired the force of a double atmosphere, we shall, before making the liquid boil, have to raise the heat to 250°. The temperature of steam of twenty atmospheres is 418°, and is equivalent to a pressure of 300 pounds on the inch. Under a still stronger pressure, water may be rendered almost red-hot, but the force with which its particles are then tending to separate, is almost that of inflamed gunpowder. It is from the want of a proper estimate of this enormous rending force that fatal accidents so frequently occur by overweighting the valves of steam boilers. Even then, however, if a gradual issue were allowed, only a certain quantity of the water would absorb and render latent the existing excess of heat above 212° and would become common steam, leaving behind a considerable portion as boiling water of the ordinary temperature.

The fact that liquids are driven off, or made to boil at lower degrees of heat when the atmospheric pressure is lessened or removed, has recently been applied to some very useful purposes.

684. The process for refining sugar is to dissolve the raw sugar in water, and after clarifying the solution by straining or otherwise, to boil off or evaporate the water again, that the dry crystallized mass may remain. Formerly this evaporation was performed under ordinary atmospheric pressure, and a heat of at least 220° was required to make the syrup boil; by which high temperature, however, a considerable portion of the sugar was discoloured and rendered uncrystallizable. In the beginning of this century, the valuable thought occurred to Mr. Howard, that the water of the solution might be drawn off or evaporated at a very low temperature by boiling the syrup in a vacuum, that is to say, in close pans, which would exclude the atmospheric pressure. This was accordingly done, and the value to the inventor of the patent right was said to have exceeded thirty thousand pounds a year. The syrup during the process is not heated to beyond 150°, and it yields either colourless crystals or loaf-sugar.

The apparatus for evaporating and distilling *in vacuo* consists of vessels strong enough to bear, when quite empty, the external atmospheric pressure. They are generally of copper and are made of an arched form. The vacuum is produced and maintained by air-pumps worked by steam-engine or other power. By an ingenious arrangement, the state of the boiling syrup can be seen through a glass let into the upper part of the vacuum pan. Hundreds of gallons may be thus seen, under the agitation produced by the air-pump and the heat, tossing about like the waves of a turbulent sea.

In the preparation of many medicinal substances the process of boiling *in vacuo* is equally important. Many extracts from vegetables have their virtues impaired, and some medicinal principles (alkaloids) are even destroyed, by a heat of 212°; but when the water used in making the extract is driven off *in vacuo*, the activity of the fresh plant remains in the product.

685. In the same manner, in the process of distillation of the essential oils of vegetables, which is merely the receiving and condensing again in appropriate vessels an aëriform matter raised by heat from the vegetable mass, those which are changed and injured by an elevated temperature, may be obtained of perfect quality by carrying on the operation in a vacuum. The essential oils of lavender, peppermint, and others are said to have their natural odour and flavour better preserved, since this plan has been adopted.

686. If the valuable apparatus invented by Howard, could be used generally in the countries where sugar is produced from the juice of the sugar-cane, more sugar than now, and of superior quality, would be obtained from a given quantity of juice. The complete apparatus, however, is costly at first, is of complex construction, and requires delicate management where skilled labour is difficult to obtain, and if damage occur, engineers capable of repairing it are far away. Complete interruption of the work from any cause would bring heavy loss to the proprietor who had trusted to the superior apparatus. Under these circumstances, it has appeared to the writer that the simple plan now to be described would in many places render service. It is merely to establish a communication between a close boiler, as *a*, and the vacuum at the top of a water-barometer, as *b* (fig. 171). To produce that vacuum, the strong vessel, *b*, forming the top of the barometer, and thirty-six feet of tube below, reaching to *d*, are first filled with water through a cock, *c*, at the top; this cock being then shut, and another cock, *d*, at the bottom, which had been shut, being opened, the water sinks down out of the vessel, *b*, until the column in the tube is only thirty-four feet high, as at *f*, that being the height which the atmosphere will support. On then opening a communication between the boiler, *a*, and the vacuum in *b*, the operation will go on as desired, and the steam rising from *a* may be condensed in *b* by a little stream of cold water allowed constantly to run through and be scattered from above.

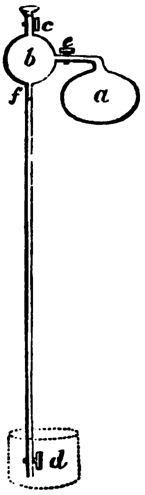

Fig. 171.

This water, it is evident, will always pass downwards, becoming part of the barometer column below, without filling up or impairing the vacuum. If air should find admittance in any way, the original degree of vacuum can always be easily reproduced as at first; and to prevent interruption from this cause, it might be convenient to have two vessels like *b*, of which one could always be in action while the other was being emptied of air. On many sugar estates there is a fall of water, fit to supply the barometer without the trouble of pumping; but even the expense of pumping by hand or horse-power would not be deemed waste for the end here sought. The tube, *d c*, needs not to be perpendicular, provided it be longer in proportion to its obliquity; and it may be very small: some yards of common lead-pipe would answer.

It will be observed that the principle here suggested for producing a vacuum is similar to that described at p. 303 (Art. 470, Sprengel's vacuum), except that mercury is there employed instead of water. The very great difficulty of erecting and preserving a water barometer is an obstacle to its employment for any industrial purpose.

687. When it was understood that, at common temperatures, water and many other liquids would be existing in the form of air or gas, but for an atmospheric pressure opposing the separation of their particles, it became of great importance in many of the arts, and for comprehending certain phenomena of nature, to ascertain exactly, with respect to some of these liquids, particularly water, the degrees of expansive force belonging to them at different degrees of temperature. The subject, as far as water is concerned, has been investigated with great care, and the following table shows part of the results. The left-hand column marks temperatures rising from 32° of Fahrenheit's thermometer, or the freezing point of water, to 418°; and the right-hand column marks the corresponding degrees of force with which the water tends to expand into the state of steam, and therefore also, the force and density in any vessel of the steam confined above the water which it contains. One ounce and a half per square inch is the expansive force exerted on the sides of any containing vessel by the steam rising from freezing water, that is to say, the force with which freezing water seeks to dilate into steam or air; and sixty pounds per inch is the force of the water heated to 290°. To many readers the idea will be quite new and surprising, that if some freezing water, or even ice, be inclosed in a bladder or bag of caoutchouc containing nothing else, and the bladder or bag be lodged in the exhausted receiver of an air-pump or other vacuum, the bladder will quickly be distended with steam strong enough to support a weight of one ounce and a half on a square inch of its surface.

At 32° force of steam is	1½ oz. per inch.
50	2¾ „
100	13 „
150	4 lbs.
180	7½ „
212	15 „
250	30 „
272	45 „
290	60 „
418	300 „

688. From this table we perceive how much more rapidly the tendency to dilate into steam increases, than the temperature of the water. A rise of eighteen degrees, *viz.*, from 32° to 50°, at the beginning of the scale, only increases the dilating force *one ounce and a quarter* on the inch, while an equal rise of 18° at the end of the scale, *viz.*, from 272° to 290°, increases it ***fifteen pounds.*** It is important to distinguish, however, between the ***tendency to form steam*** at any temperature, and the ***quantity of steam*** produced by a given quantity of heat; for the imperfect understanding of this matter has led to many vague schemes for improving the ***steam-engine.*** The fact is, that ***high pressure steam*** is merely ***compressed steam,*** as ***high pressure air*** is ***compressed air;*** in other words, the density of steam is greater, or there must be more of it in a given space, exactly as its force is greater, according to the rule explained at page 247; and the heat expended in its formation being proportioned to the quantity of steam in a given space, or the density, the force and the cost in fuel have always nearly the same relation to each other. In one pint of steam at 290°, having an elastic force of sixty pounds on the inch, there is very nearly four times as much water and four times as much latent heat as in one pint of steam at 212°, which has a force of fifteen pounds on the inch,—indeed, the one pint at 290° may be changed into the four pints at 212°, or the contrary, by merely lessening the pressure. It does not accord with the plan of this general work to enter farther into the details of this subject, but they may be found in all treatises on the steam-engine.

689. Because water, or any liquid under the pressure of the atmosphere, while receiving heat, remains tranquil, and apparently unchanged, until it reaches what is called its boiling point, at which the bubbling or conversion into vapour takes place, we might deem that temperature necessary, under any circumstances, to enable it to assume or to maintain the form of gas or vapour. But this is no more true than that a common spring compressed by any obstacle or force, has no tendency to expand until the moment when at last it overcomes the obstacle. Liquid water with heat, to whatever amount, is really a spring compressed by a weight of atmosphere, and seeking to expand itself into steam with a force proportioned to its temperature. Even at 32°, or its freezing point, as is found by placing it in a vacuum, it assumes a gaseous form, with a force or pressure of 1½ ounce for every square inch of its surface, and is restrained from giving out more only by the counter-pressure of that which has escaped; and at any higher temperature, to correspond with the greater power of dilatation, the restraining force must also be greater: at 100°, for instance, it must be 13 ounces on the inch; at 150°, 4 lbs.; at 212°, 15 lbs.; at 250°, 30 lbs.; and so on, as above stated. When the restraining force is considerably weaker than the expansive tendency, the formation of steam takes place rapidly, not from the surface only, but also from within the substance of the liquid, so as to produce the bubbling and agitation called *boiling*. It is because the atmosphere or ocean of air which surrounds the earth happens to have in it 15 lbs. weight of air over every square inch of the earth's surface, and presses on all things there accordingly, that 212° has come to be called the boiling point of water. An atmosphere less heavy would have allowed water and other liquids to expand into vapour at lower temperatures, and an atmosphere more heavy would have had a contrary effect. Were there no atmosphere, a temperature of 70° would be the boiling point of water.

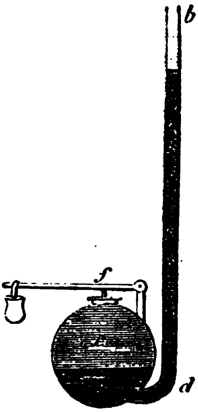

Fig. 172.

690. The exact degree of expansive force for every degree of temperature in liquids has been ascertained in various ways; for instance, by heating them in vessels furnished either with fitly-loaded valves, as at *f* in fig. 172, or in vessels having from the bottom a tall upright tube, as *d b*, into which water in the upper part may force a column of mercury from below to an elevation, marking exactly the expansive tendency—the valve or the mercury being of course, for the time, protected from the external atmospheric pressure, or the necessary allowance being made for that pressure.

Water placed on the fire in a vessel from which steam cannot escape may be rendered almost red-hot without a bubble forming or one particle being dissipated; but the tendency to expand into steam is then great enough to burst the strongest vessels. The Marquis of Worcester exploded a cannon by shutting up water in it, and then surrounding it with fire. The bursting of steam boilers is an accident which frequently occurs, the sides of the boiler not being strong enough to withstand the pressure of the steam generated therein.

As water at any temperature is tending to dilate itself into steam, with a force proportioned to the temperature, the temperature of the water in the boiler of a steam-engine indicates the degree of force with which the steam is acting on the piston.

The reason that high-pressure steam issuing from a boiler heated to 300° or more affects a thermometer only as low-pressure steam from a boiler at 212° is, that in the instant when such steam escapes into the air, it expands until balanced by the pressure of the atmosphere, that is, until it becomes low-pressure steam, and it is cooled by the expansion, as air is cooled on escaping from any condensation. Further, in rushing against the thermometer, it carries much of the surrounding cold air with it. The hand may be held in such high-pressure steam while escaping without any danger of scalding.

691. *The Steam Gun.*—In the construction of the *steam gun*, a gun-barrel is connected with a high-pressure steam-boiler, in the same manner as with a chamber of condensed air; and as the steam may be generated continuously as long as water remains in the boiler, if bullets be allowed to fall into the barrel fast enough, a hundred or more may be thrown out every minute with the same force and precision as if each issued from a common fire-arm. The rapid succession resembles the issue of water from a jet-pipe; and if such an engine could be brought to act in a field of battle, its barrel of death, made to point gradually along a line of men, would mow them down like corn-stalks before the scythe. The horrid idea and the proposal have been excused by saying that to show the possibility of such destruction would have the effect of putting an end to war altogether. In recent wars the modern *mitrailleuse* has been substituted for the steam gun. It consists of a number of barrels in the form of a gun, each charged with powder and shot. These admit of a simultaneous discharge. Within a certain range the effect is as above described, a number of men are mown down in an instant.

The invention of gunpowder, with the consequent change of military tactics, because it gave to a handful of men possessing it, the mastery over thousands who had it not, was hailed by the thoughtful men of the day as a certain security against the relapse of civilized mankind into such barbarism as followed the irruption into Europe of the Goths and Vandals. It was thought that only well-instructed and disciplined armies could now overrun a European kingdom. This consideration, however, has less interest since the invention of printing, and other changes in the world, have afforded still better and more humane securities.

692. *The Modern Steam-engine,*

During the lives of people still living, has changed the character of human industry, and may almost be said to have elevated man in the scale of existence.

The name of *steam-engine*, to most persons, brings the idea of a machine of the most complex nature, and hence to be understood only by those who will devote much time to the study of it; but he who can understand a common pump may understand a steam-engine. It is, in fact, only a pump in which the fluid passing through it is made to impel the piston instead of being impelled by it, that is to say, in which the fluid acts as the *power* instead of being the *resistance*. It may be described simply as a strong barrel or cylinder, *c d*, with a closely-fitting piston in it, here shown at *b*, which is driven up and down by strongly expansive steam admitted alternately above and below it from a suitable boiler; while to the end of the piston-rod, *a*, at which the whole force may be said to be concentrated, there is attached in some convenient way, the work which is to be performed. The power of the engine is of course proportioned to the size or area of the piston, on which the steam acts with a force, according to its density, of from 15 to 100 or more pounds for each square inch. In some of the Cornish mines, and in great steam-ships, there are cylinders and pistons of more than ninety inches in diameter, on which the pressure of the steam equals the effort of from six hundred to one thousand horses.

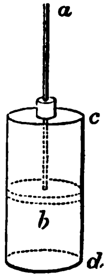

Fig. 173.

It is very interesting to review the steps by which the newly-awakened power of steam has been adapted to the different kinds of labour in which it is now employed. The first, being the most obvious application of a force moving alternately up and down, was to the pumping of water on a great scale. This had to be done in mines, many of which would be valueless if the water constantly draining into them could not be removed at a moderate cost. It has to be done also in supplying and distributing water in towns. Now at the mouth of many a mine may be seen the wonder-working piston-rod connected with one end of a great vibrating beam, to the other end of which a huge water-pump is attached, which sends out a torrent from the bowels of the earth of many thousand gallons of water at each stroke of the piston-rod. Again, a single engine pumping from a pure stream or deep well, at a distance perhaps of miles from a city, suffices to maintain an abundant supply for all the reservoirs, baths, fountains, &c., of a numerous population. A next step in advance was the addition to the powerful piston-rod of the crank and ponderous fly-wheel, by which the interrupted up-and-down strokes were converted into a smooth turning or rotatory motion, as uniform as that of a wheel driven by a waterfall, and thus it became applicable anywhere to the working at small cost of all kinds of machinery, such as water-power and other powers had worked before. One steam-engine, now stretching long arms over a great barrack or manufactory, keeps in one quarter thousands of spinning-wheels in motion, while in another it is carding and preparing the material of the thread, and in another weaving the cloth.

One steam-engine in a great metropolitan brewery may be employed by turns in grinding the malt, pulling up supplies of all kinds from waggons around the building, pumping cold water from deep wells into some of the coppers, sending the boiling wort from others to the cooling floors or apparatus above, lifting the casks about, loading the drays, and so forth—in a word, performing alone or aiding in the labours of a multitude of distinct workers. There soon sprang up corn-mills, saw-mills, block-making machines, coining machinery, printing-presses, and numberless other such things, all moved by steam. Some of these now accomplish works of such magnitude as, but for the resistless force of steam to aid them, men would never have attempted; for instance, where huge mechanic hands take hold of heated lumps of iron and quickly afterwards return them rolled into thin sheets, or formed into uniform bars and rods, as if the iron had become to them like soft clay in the hands of the potter; or, as in the manufacture of Armstrong guns, vast coils of red-hot iron weighing many tons are raised and rolled around a core, to build up one of those mighty pieces of artillery. After a time came, what many persons regard as the greatest marvel of all—the application of steam to locomotion. At this time, over a great part of the world, the piston-rod with its crank is on land driving, with the speed of the wind in all directions, railway trains loaded with passengers and merchandize, and on the water is propelling by paddle-wheels and screws innumerable steam-ships. These ships, setting at defiance the violence of winds and waves at sea, and the currents of the fleetest rivers traversing the lands, are carrying men and civilization over the whole globe

Many regions, until lately little known beyond their own confines, are now by the steam-engine called, so to speak, from their solitude to become parts of the one great garden of the earth which civilized man will fully cultivate. Such are the prodigies which Watt's invention has already effected, and new applications are still daily being made.

693. The following account of the parts of the steam-engine is intended, without entering into minute practical details, to explain the principle or general nature of the machine. It should serve to render very interesting to an attentive reader a visit to any place where a steam-engine is in use. To avoid complexity in the figure, the parts which the reader can easily conceive, as the walls of the building and the framing of the machine, are not here sketched.

1st. The part which first claims attention is the great cylinder, *c d* (fig. 174), already spoken of as the main portion of the machine, in which the *piston*, P, is moved up and down by the action of steam entering from the boiler, alternately above and below it, through the pipes, *e c* and *e d*. The barrel or cylinder is bored with extreme accuracy, and the piston is padded or packed round its edge with greased hemp or other soft material, or has the metallic packing of iron rings which cause little friction, so as to be perfectly air or steam-tight. 2nd. The next part to be mentioned is the *boiler*, B, which is made of suitable size and strength. 3rd. The steam passes from the boiler along the pipe to *e*, and there, by suitable *cock* or *valves*, worked by the engine itself, is directed alternately to the upper and under part of the barrel; and while it is entering to press on one side of the piston, the waste steam is allowed to escape from the other side, either to the atmosphere, for high-pressure engines, or into, 4th, the *condenser* at C, for condensing engines; the condenser being always kept at a low temperature by cold water jetting into it and pumped out again by the piston *k*. 5th. *The supply of steam* from the boiler to the cylinder is regulated by a *throttle valve* placed somewhere in the pipe, B *e*, and made obedient to what is called, 6th, the *governor*, a contrivance not represented here, but already described in Art. 159, to illustrate centrifugal force. It consists of two balls hanging by rods jointed together like the legs of a tongs, from opposite sides of an upright spindle, which is made to revolve by connection with some turning part of the machinery; when that spindle is turning at all faster than with the desired speed, the balls fly more apart, and thereby move the steam valve so as to narrow the passage; and on the contrary, when it turns more slowly than desired, they collapse, and by so doing open the valve wider. 7th. The *supply of water* to the boiler is regulated by a *float* on the surface of the water in the boiler; which float, on descending to a certain point, because of the consumption of water, opens a valve to admit more. 8th. There is a *safety valve* in the boiler, *viz.*, a well-fitted flap or stopper, held against an opening by a weight, which allows the valve to open whenever the steam acquires a certain tension, and before danger can arise from the overheating of the water. 9th. The *rapidity of the combustion*, or force of the fire, may be exactly regulated by the state of the boiler and the wants of the machine in various ways, one of which is to have a small tube (not represented here) rising from the boiler, closed by a loaded piston, which, when the water in the boiler becomes too hot, and the steam therefore too strong, is caused to narrow a little the chimney-valve, or *damper;* the draught is then diminished and the fuel saved, until a brisker fire is again required. 10th. In this figure, *a i g* marks the place of the *great beam*, turning on an axis at *i*, and transmitting the force of the piston to the working machinery. When the labour is to pump water, the pump-rods are simply connected with the end, *g*, of the beam; but when any rotatory motion is wanted, the end, *g*, is made to turn—11th, a *crank*, *l n*, by the rod, *g l;* and uniformity of motion is obtained by the in-

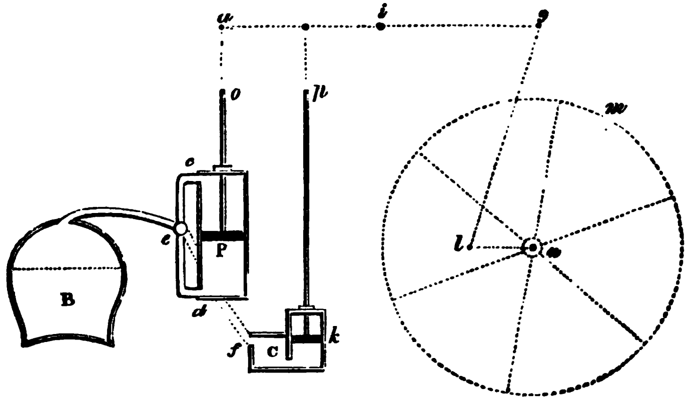

Fig. 174.

fluence of—12th, the great *fly-wheel, m* (Art. 257), fixed to the axis of the crank.

694. The smallest and simplest steam-engine, and therefore the cheapest, is that called the *high-pressure engine.* In it steam is used of great density, and consequently of great force, as of 50 lbs. or more to the inch ; and while the fresh steam is admitted to press on one side of the piston, the steam which has already worked is allowed to escape, or is driven out to the air through a valve opened on the other side. The succession of semi-explosions or puffs of condensed vapour seen and heard when a railway locomotive engine passes, marks the escape of the used steam. The atmospheric resistance to the issue of the steam diminishes the working force of the piston just 15 lbs. per inch. The simplicity of this form of engine recommends it, but the danger of having one large boiler of overheated water seeking to escape, has led to the adoption in many cases of small boilers, consisting chiefly of strong tubes communicating with one another, so that the bursting of one of them is not attended with the same danger as when the accident occurs to one large boiler.

695. In the low-pressure engine with large boilers, steam may be used of force not exceeding 20 lbs. on the inch, which force is only 5 lbs. more than the atmospheric pressure, and would not require a boiler of great strength : but as the interior of the low-pressure engine is kept in a state of vacuum, except where the steam is acting, nearly the whole pressure of 20 lbs. is made available, and the engine has the same power, if of equal size, as a high-pressure engine working with steam of 35 lbs. on the inch. The required vacuum is preserved by means of a separate vessel or box, represented at C, called the *condenser*, into which a small stream of cold water is constantly rushing to condense the steam, and is afterwards pumped out with the condensed steam, and with any little air that may have entered : the pump is represented at *k* in the figure. Steam on coming in contact with a cold body is condensed almost with the rapidity of an explosion ; and therefore the instant that opened valves make a communication between the cold condenser and any part of the engine containing steam, this rushes to the condenser, and becomes water, leaving a vacuum behind. The grand improvement by Watt was in the contrivance of this separate condenser, for, until his time, cold water had always been thrown directly into the working cylinder, cooling it so much, that twice or thrice its fill of steam was destroyed at each stroke to warm it again before it could work. This single change saved more than three-fourths of the quantity of fuel formerly expended

696. Before Watt's day, the only steam-engine in use, and which was employed almost solely for pumping water, was a rude *single-stroke engine*, as it was called, in which steam, admitted under the piston to raise it, aided the weight of the pump-rods at the far end of the beam, and that steam being then condensed so as to leave a vacuum in the cylinder, the pressure of the atmosphere above pushed the piston down to do its work: on this last account the engine was also called an *Atmospheric engine.* This engine wasted so much fuel, from causes of which the chief is mentioned in the last paragraph, that the expense was not much less than that of employing horses.

In this atmospheric engine, the steam which lifted the piston against the atmospheric pressure, required to be at least as strong as that pressure, to the very end of the stroke. Another of Watt's great improvements was, his not allowing atmospheric air at all to enter the cylinder, and thereby maintaining always a vacuum on the side of the piston where steam was not working, by which procedure he not only avoided the cooling effect of the air, but was at liberty to shut off the steam, as it is expressed, or to stop the supply for each stroke, before the cylinder was full, and then to make the further expansion of the quantity admitted impel the piston to the end of the stroke.

697. This principle of causing the mere farther expansion of a certain bulk of steam to do work was afterwards carried to a great extent by Messrs. Hornblower, Woolfe, and others, who constructed engines with two barrels, in the first and smaller of which the steam was made to act in its dense or strong state, as it issued from the boiler, and when it had finished a stroke there, instead of being at once sent useless to the condenser, it was admitted to a larger piston, which it moved by its continued expansion alone :—the same steam thus doing double work or more. Nearly all the advantages of the two cylinders, however, are obtainable from the single cylinder, as now used in most of the Cornish mines. Steam of about 60 lbs. pressure on the inch is admitted to the cylinder, until the piston is driven nearly one-third of its way, and the admission valve being then shut, that measure of steam is left to finish the stroke merely by its expansion. The pressure of the expanding steam gradually diminishes, it is true, in proportion as the volume increases; but in pumping water there is a great saving of time, from having the power more intense at the beginning of the stroke, when the vast mass of water and machinery has first to be put in motion. Steam while doubling its volume by mere expansion, will do about ***two-thirds*** as much work as while originally rising from the boiler, and by subsequent doublings, it might add to the effect of the first: the increasing size of the cylinder, however, and increased friction, confine this mode of using steam within moderate limits.

It might be supposed that high-pressure engines without condensers would be very wasteful, because in them the steam which has acted must be driven out of the cylinder against the powerful resistance of the atmosphere, while in the low-pressure engine it has instant access to the vacuum of the condenser, and so leaves effective the whole pressure of the fresh steam on the opposite side of the piston. But as in the low-pressure engine, a considerable part of the power of the steam is expended in overcoming the friction and other impediments of the numerous and bulky parts, while in that of high-pressure, the parts are much fewer and smaller in proportion to the force exerted, the loss from friction, &c., is much less than might be expected.

698. From misapprehension of the law of increase of force by increase of heat in water, explained by the table at Art. 687, some exceedingly false conclusions have been drawn, and acted upon at great expense, in attempts to make engines work with an excessively high pressure. Besides making the error now alluded to and others, projectors have overlooked the fact, that we possess no material for cylinders and pistons strong enough to bear the intensity of pressure, heat, and friction contemplated even for a moderate time. Perhaps more striking examples could not be adduced of the grave errors into which even highly ingenious men may fall, when not sufficiently attentive to the general truths of nature, on which the arts which occupy them are founded, than in the history of supposed inventions and improvements connected with the steam-engine.

The fertile genius of James Watt did not stop at the accomplishment of the two or three important particulars described above, but throughout the whole detail of the component parts and the management, in various applications of the engine, he contrived prodigies of simplicity and usefulness. The prescribed bounds of this work would be exceeded by entering more minutely into the subject; but it may be remarked that, in the present more perfect state of the engine, it appears a thing almost endowed with intelligence. It regulates with perfect accuracy and uniformity the *number of its strokes* in a given time, *counting* or *recording* them moreover, to tell how much work it has done, as a clock records the beats of its pendulum;—it regulates the *quantity of steam* admitted to work;—the *briskness of the fire;*—the *supply of water* to the boiler; the *supply of coals* to the fire;—it *opens and shuts its valves* with absolute precision as to time and manner;—it *oils its joints;* it *takes out any air* which may accidentally enter into parts which should be vacuous;—and when anything goes wrong which it cannot of itself rectify, it *warns its attendants* by ringing a bell:—yet with all these talents and qualities, and even when exerting the force of hundreds of horses, it is obedient to the touch of a hand;—its aliment is coal, wood, charcoal, or other combustible;—it consumes none while idle;—it never tires, and wants no sleep;—it is not subject to malady when originally well made; and only refuses to work when worn out with age;—it is equally active in all climates, and will do work of any kind;—it is a water-pumper, a miner, a sailor, a cotton-spinner, a weaver, a blacksmith, a miller, &c., &c.; and a small engine in the character of a *steam-horse* may be seen dragging after it on a railroad a hundred tons of merchandize, or a regiment of soldiers, with four times the speed of the fleetest coaches of old. It is the king of machines, and a permanent realization of the *Genii* of Eastern fable, performing supernatural feats at the command of man.

We need not wonder that the inventor of an engine having such qualities should be deemed deserving of the highest honours which his fellow-men could bestow. In November, 1825, a public meeting was held, to vote a monument to WATT, then recently deceased; and the most distinguished men of the empire, of all parties, philosophers, and statesmen, met to vie with one another in speaking his praise. Eloquent indeed were the discourses pronounced; but perhaps in the progress of civilization, there can rarely be offered such motive and occasion. The common voice of that assembly scarcely exaggerated, when attributing to Watt's genius and perseverance that increase of our national commerce, and riches, and power which had enabled free Britain, almost single-handed, at an extraordinary crisis of human affairs, to contend with Europe combined against her, and at last to triumph, securing thereby her own well-being, and probably advancing that of the human race.

699. *Papin's Digester.*—The vessel so called is a very strong iron pot or boiler, which can be kept closed by a regulating valve against the force of the steam formed within it; and in such a vessel, water can be heated considerably beyond the ordinary boiling point,—sufficiently, for instance, to dissolve and extract all the gelatin or the animal matter of bones immersed, and so to form from them a rich soup where ordinary boiling would get nothing.

The cook who increases the fire under a boiling pot not closed, with the hope of making the water hotter, is foolishly wasting the fuel, for the water can only boil, and it does boil at 212° of the thermometer, the surplus heat being carried away in the steam.

As different substances, under any given pressure, become aëriform at different temperatures, mixtures of such may be decomposed by heat. If a mixture of alcohol and water, for instance, be placed over a fire, the alcohol will boil off long before the water; and if the vapour be directed into a cold tube or vessel, it takes the liquid condition, and the operation is called *Distillation.* In a mixture of ether, alcohol, and water, by using a cooling apparatus for the vapour and taking care that the temperature does not exceed 96°, the greater part of the distillate, or liquid distilled, will be ether; if under 174°, alcohol; and at 212°, water.

700. *The Cryophorus.*—The little instrument called the *Cryophorus* (or carrier of cold) is represented in fig. 175. It serves to illustrate some of the principles above set forth. It consists of a bent glass tube blown into bulbs at the ends, *a* and *b*. Some water is introduced so as partly to fill one bulb. This is boiled, and the steam expels the air. It is then hermetically sealed. There will always be in the apparently empty part a quantity of watery vapour of a density depending on the temperature. If one of the bulbs be heated more than the other, the steam over water in that one will, for the reason stated above, be denser and stronger than in the other, and will, therefore, be forcing its way into the other; where, owing to the lower temperature, a part of it will be constantly relapsing into the state of water, and making room for more. Hence, if the difference of temperature between the bulbs be long maintained the whole water will, by a sort of distillation, gradually

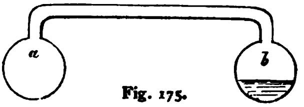

Fig. 175.

pass into the colder bulb. Two other remarkable facts which this instrument can exhibit are—1st, that if held with the tube nearly level and undermost, the warmth of a hand grasping one bulb will form steam, causing all the water to pass rapidly to the other, and to boil there; and 2nd, that by dipping one of the bulbs, nearly empty, into a freezing mixture, the continued condensation of the vapour within will so cool the water in the other bulb, as to cause it to freeze or become ice.

701. The cold produced by evaporation may be demonstrated by other experiments. Water dropped on the hand produces a sense of coldness while evaporating. Alcohol, ether, and chloroform, by their greater volatility, produce a more marked sensation; while the sulphide of carbon, by its rapid evaporation, produces a painful degree of cold. If a small quantity of this liquid is placed in a saucer, and some slips of filtering paper are introduced, the sulphide is rapidly absorbed and conveyed by capillary attraction to the fibres at the extreme end of the paper. The cold resulting from the evaporation is here so great that the vapour, with the moisture of the surrounding air, is deposited in white snowy-looking crystals on the edges of the paper.

702. When a liquid has reached the temperature at which it boils, that is to say, at which its power of emitting vapour becomes rather more than a balance to the atmospheric pressure, its dilating force is very strong. A weight of 15 lbs. on the square inch, which is the ordinary atmospheric pressure, is equal to 2160 lbs., or nearly a ton, on a square foot; and such is the power with which the vapour of all boiling substances open to the air, rises from them, that, in a large steam-engine this is sufficient to urge the piston with a force of 600 horses! But at temperatures far below boiling, the tendency to expand, as already stated, is still very great, and although not attracting common attention, is silently working most important ends in the economy of nature. As freezing water, or even solid ice, emits in a perfect vacuum, a steam or vapour which can lift an opposing weight with a force of 1½ ounce per inch, or 16 lbs. on a square foot, so also do many other liquids and solids. Thus, in the apparently empty space called the Torricellian vacuum, existing over the mercury in a barometer tube, there is always the vapour of mercury, more or less dense in proportion to the temperature; and around camphor, the essential or volatile oils, and other volatile liquids, there is always an atmosphere of the substance, in the form of gas or vapour, whether in otherwise empty space, or mixed with common air. This is demonstrable in camphor by throwing freshly broken fragments of that substance on perfectly clean water. It is light and floats, and the vapour constantly given off from the surface causes it to move about with great rapidity, and to perform a number of remarkable gyrations. If some portions are ignited, they will move about like miniature fire-ships.

703. It had long been known that solids and liquids placed in a vacuum emitted quickly, in the form of vapour, a quantity of their substance proportioned to their temperature; but Dalton made the important discovery that in a space containing air, these vapours arise in quantity the same as if air were not present—the two fluids seeming to exist there independently of each other, with the exception, however, that in a vacuum, the equable diffusion of a vapour takes place at once, while in a space already occupied by air, it proceeds more slowly, as the vapour has to force its way through the particles of the air, and it then takes place by a tranquil evaporation from the surface of the liquid, instead of by the agitation of ebullition. In an apartment with an open vessel of water in it there is soon mingled with the air, although invisible, a watery vapour, as dense as if the room had been a vacuum at the same temperature. The following are consequences of this important truth :—

That it is only the atmosphere of any volatile substance, which by pressing on the mass of it can prevent its further dissipation by heat. Thus camphor, musk, essential oil, spirits, water, &c., can be preserved only by placing them in closed bottles or vessels, in which, in addition to the air present, an atmosphere of their own vapour is formed, by which further evaporation is checked.

The important process of drying any moist object is merely the placing it under an elevated temperature if attainable, and in an atmosphere not containing so much moisture as to be saturated at the temperature. The effect of wind or motion of the air in quickening evaporation is owing to its removing air charged with the moisture, and substituting fresh air which is not so charged. Damp clothes cannot be dried in a close room; for so soon as the air is saturated with moisture, no more vapour is emitted.

If air at a certain temperature contain mixed with it as much water as can be sustained in the form of invisible vapour at that temperature, and if then, by any cause, as rising in the atmosphere, the air be cooled, it will abstract heat from the vapour, and cause a portion to be precipitated or visibly condensed into a fog or rain. Water rising as invisible vapour from the surfaces of lakes or rivers, often, when it has reached a certain height and is thereby cooled, condenses into the stratum of mist or clouds which there appears, and which for a time may be usefully protecting the fields from the intense meridian sun, or may fall again as refreshing showers over the country.

It is the tranquil and invisible evaporation of which we are now speaking, which lifts from the surface of the globe all the water which, after condensation, returns to the ocean in the form of the myriads of river streams that give life and beauty to the face of nature.

704. There are other instances of vapour which is invisible while at a certain moderate temperature, but is copiously precipitated when the air with which it is mixed is cooled, or when it touches a colder solid body ; among these may be mentioned the steam observed at night and morning hovering over brooks and marshes heated by the sun during the day :—the frost-smoke, as it is called, which lies on the whole face of the Greenland seas in the beginning of winter, where the water, warmed by the long day of the polar summer, continues to emit its vapour for a considerable time after the summer is past, into an atmosphere become too cold to preserve it in an invisible form :—the breath or perspiration of animals, of horses in particular after strong exertion, becoming so strikingly visible in cold and damp weather, or even in warm weather, when the air is already charged with much moisture :—in cities where there are deep drains communicating with kitchens, manufactories, &c., and constantly filled with moist and warm air ; the vapour-loaded air, although clear or transparent in the drain, immediately on escaping into a frosty atmosphere, lets go its moisture, with the appearance of steam issuing from a great subterranean cauldron. Steam over water in any boiler is transparent or perfectly aëriform—as may be seen when water is made to boil in a glass flask with a long neck ; but as soon as it is cooled, by contact or admixture of air colder than it, it ceases to be true steam, and is condensed into small particles of water, visible spherules suspended in the air. Many persons, while thinking of steam, figure it only in this last-mentioned visible condition, of particles of water mixed with air nearly as a subtle powder might be mixed. Until steam is cooled and condensed, it is of a nature to fill alone any appropriate vessel and powerfully to distend it, just as air fills and distends a bladder. Steam issuing from the spout of a tea-kettle is hardly seen near the mouth, but as its distance from the spout increases, it is cooled into a jet of thick cloud or vapour.

705. In a vessel from which air, and therefore atmospheric pressure, is excluded, even the temperature of freezing water is sufficient to maintain permanently in the state of invisible gas, many substances which exist as liquids under this pressure. A large mass of any such liquid when placed in a vacuum, is not instantly converted into gas, because the portion which first rises becomes an atmosphere compressing what remains, and because, moreover, that portion, by absorbing from the mass much heat in the latent state, cools for a time the remaining mass. We see, therefore, why liquids are so rapidly cooled when placed wherever a vacuum can be made and maintained; that is to say, where, after common air has been removed, the aëriform matter rising from the liquid and absorbing its sensible heat, is also promptly and continuously abstracted. It is thus that water placed in the exhausted receiver of an air-pump is so rapidly cooled, and that when there is placed beside the water, a vessel of concentrated sulphuric acid, or other substance capable of absorbing the watery vapour as it is formed, the water is soon reduced to the state of ice. The following experiment will furnish on a small scale an additional illustration. Blacken the interior of a watch-glass by holding it over the flame of burning camphor. Drop into this when cold one drop or more of water. Owing to the deposit of carbon, the water coheres in a globule, like the globules of dew on the hairy or downy leaves of plants. Place this under the receiver of a good air-pump and exhaust it rapidly. By the evaporation from the entire surface of the globule, conjoined with the cooling effect of radiation, the water is soon transformed into a solid pellet of ice. This represents the artificial production of a hailstone. Water placed in a thin glass vessel, surrounded by ether or sulphide of carbon, evaporating in a vacuum, is also quickly frozen.

It has already been explained, that in a liquid there is the same tendency to evaporate, whether it be or be not exposed to the air, so we see the reason why all evaporation is a cooling process. The effect, however, in air is neither so rapid nor so great as in a vacuum, first, because the presence of the air impedes the spreading of the newly-formed vapour from the liquid surface, and keeps it where its pressure resists the formation of more vapour; and, secondly, because the air in contact with the liquid gives a part of its heat to the liquid.

706. The conversion of sensible into latent heat by the evaporation which goes on from the sea and earth in all warm climates greatly tempers the heat of these climates, and the vapour afterwards spreading to the poles, as explained under the head of *Winds* (Art. 449), carries warmth thither to be given out as the vapour is condensed into the form of rain, or is solidified as snow. The formation anywhere of mist or rain warms the supporting air by the liberation of the latent heat from the precipitated vapour. Again, the water which, during winter, is converted into snow or ice, may be regarded as a reservoir of latent heat, which is given out and tempers the frosty air of the cold season. In the following spring such ice and snow may thus serve as receptacles in which the first violence of the returning sun may hide or expend itself. The vast masses of ice and snow among high mountains, as among the Alps and Pyrenees, serve often during the summer as stores of mild temperature to regions around: for, besides cooling the air near them, they are the never-failing sources of the cool rivers which run thence during the whole of summer, carrying freshness throughout distant lands.

707. In artificially raising temperature, we generally cause the liberation of heat which had been previously latent; and in lowering temperature or producing cold, we are generally rendering latent a quantity of heat which had previously been free.

When dwelling-houses, green-houses, or manufactories are warmed by the admission of steam into systems of pipes which are distributed over them, the heat which they emit, is that which was previously *latent* in the steam, and which spreads around as soon as the steam, by touching pipes of lower temperature, is condensed to the state of water.

708. Again, for producing cold artificially, the processes generally involve the conversion either of a solid into a liquid, during which it takes in and hides in its new constitution, as latent heat, much of the heat previously sensible in it, and in the liquid which dissolves it; or of a liquid into vapour, during which heat equally becomes latent. Thus by dissolving a salt—nitre, for instance—in water, we obtain a solution which is very cold. In India a common mode of cooling wine for table is to surround the bottles with nitre dissolving in water; and the water of the solution being evaporated again before the next day, the salt is ready for use as before. If nitrate of ammonia is substituted for nitre, this salt, by reason of its greater and more rapid solubility in water, produces a much greater degree of cold. Equal parts of powdered nitrate of ammonia, crystallized carbonate of soda, and water, cause a reduction of temperature from 50° above, to 7° below the zero of Fahrenheit.

Similar results are produced by the liquefaction of salts in acids. Thus eight ounces of sulphate of soda finely powdered, rapidly dissolved in five ounces of the strongest hydrochloric acid, form a convenient freezing mixture which may be obtained at all temperatures independently of ice and snow. In sufficient quantity it will lower the thermometer from 50° to near zero.

709. By taking advantage of these principles, the same substances may be made to produce great heat or an intense cold, according to the proportions in which they are used. If one part of broken ice by weight be rapidly mixed with four parts of strong oil of vitriol, the ice instantly disappears, and the water formed combines with the acid, producing a heat of 170°. Phosphorus takes fire on being brought in contact with the glass containing the mixture, and if ether in a tube is plunged into it, the ether boils, and a large quantity of inflammable vapour is evolved. On the other hand, if four parts of ice are rapidly mixed with one part of oil of vitriol, the ice is rapidly liquefied, and intense cold is produced, so that there is at first a deposit of dew and then of frozen water like snow, on the outside of the vessel.

Certain saline compounds readily combine with water in the solid form of ice, and cause it to pass rapidly to the liquid state ; and as in this case both the water and the salt render heat latent, the fall of temperature is doubly great. Thus, common salt at 50° and snow (or powdered ice) at 32°, when mixed, dissolve into liquid brine 37° colder than freezing water, or 5° below the zero of Fahrenheit. This action of salt on ice leads to the common practice of sprinkling salt on an ice-covered pavement before a street door, or in the roads to clear away the ice. The salt and ice quickly combine and form liquid brine, which either of itself runs off into the gutter and disappears, or is easily swept off.

Salt has been largely used in some of the London parishes during the winter season for the purpose of removing ice and snow from the public roads. According to Dr. Whitmore, in one London parish alone, seventy-seven tons of salt were used to remove the snow of two snowstorms occurring in December, 1875, and January, 1876. It produced 2234 loads of liquefied matter, which were carted away at a cost of £620. While salt is thus useful in liquefying the snow and ice, it has the effect of lowering the temperature of the air around, and it produces a liquid mixture, many degrees below the freezing point. This is injurious to pedestrians as well as horses. It penetrates boots and shoes, renders them cold to the feet, and prevents them from becoming dry.

There is less objection to the use of crude chloride of calcium in the summer. This cools the road, and maintains a degree of moisture which keeps down the dust.

> "*For any given substance, the changes of state from solid to liquid, and from liquid to air, happen, under similar circumstances, so precisely at the same temperature, that they mark fixed points in a general scale of temperature, and enable us to regulate and compare our various Thermometers.*"

710. As we can neither weigh heat, nor measure its bulk, nor see it, and as, even if our sense of touch were a correct judge in the matter, which it is not,—we dare not touch things that are very hot or very cold,—some other expedient is required for estimating the presence in bodies of this very subtle agency; and that has been found in the measuring of its most obvious and constant effect, namely, that dilatation or expansion of bodies, which again ceases when the heat is withdrawn. Any substance, solid or liquid, which will allow this expansion to be accurately measured, becomes to us a *Thermometer*,* or *measurer of heat.*

In *solid* substances, the direct expansion by heat, is so small as to be seen or measured with difficulty. In *air*, again, the expansion is very great; but there is the objection that in any apparatus yet contrived, which will allow this completely to appear, the air cannot be protected from the varying pressure of the atmosphere—an influence which affects its volume as much as changes of temperature.

711. The first thermometers constructed were of this kind. The invention of the instrument is ascribed to Sanctorio, of Padua, about the year 1600. It is represented in fig. 176. Coloured water was introduced so as to fill one-half of the bulb, A, and the liquid rose or fell according to whether the air in the bulb was heated or cooled. Very slight changes of temperature are indicated by this instrument. The hand applied to A rapidly expands the air, and causes the coloured liquid, which in the drawing half fills the bulb, to descend in the tube, B, and ascend in C D. A paper scale marked in divisions may be fixed to the tube, C D. As the tube is open at the top, the liquid rises and falls by changes in barometrical pressure. Observations of very slight changes of temperature may, however, be rapidly made with this instrument. It is so sensitive that a number of persons entering a large room will soon cause the liquid to rise, by the heat radiated from their bodies.

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* From the Greek, θέρμη, heat, and μέτρον, a measure.

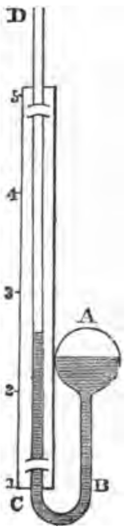

Fig. 176.

Liquids appear to have been first used for measuring temperature by the Florentine Academicians about 1650. They enclosed spirits of wine in sealed tubes, and constructed a scale which was divided into 100 parts, but as there were no fixed points, it was practically useless. It was discovered by Hook that ice always melted at the same temperature, and that, under a given atmospheric pressure, water, boiled in a metallic vessel, always indicated the same fixed temperature. Making use of these facts, Sir Isaac Newton proposed as fixed points of comparison, the points of freezing and boiling water. Bearing these facts in mind, the construction of the thermometer will be easily understood.

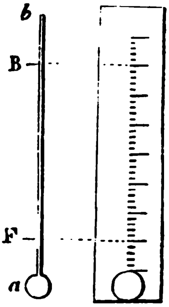

Fig. 177.

712. A small quantity of the liquid selected, alcohol or mercury, is placed in a glass bulb, as *a* (fig. 177), having a long neck or tube, *a b*, into which it may rise to be measured when expanded by heat. Among liquids, mercury is, on several accounts, peculiarly suitable. The use of this was first suggested by Fahrenheit, of Dantzic, in 1720. In it, the range of temperature between freezing and boiling, is greater than in any other liquid, and it reaches a lower point without solidifying than any other, except alcohol or ether. Its little capacity for heat, and its great conducting power, cause it to be very quickly affected by changes of temperature. Again, its expansion is singularly equable for an equal increase of heat through the important middle part of the scale, which includes all the common temperatures on earth, namely, from the freezing to the boiling heat of water. Owing to the non-adhesion of mercury to glass it may be used in very minute tubes, as capillary attraction does not interfere with its movements. It is easy to proportion the bulb and the tube to each other, so that a small difference of temperature shall cause the mercurial column in the tube to rise or fall very conspicuously.

Now when the important fact was ascertained that solid water or ice always melts at precisely the same temperature, and that liquid water boils always at the same temperature, it followed that, by placing such a thermometer as above described, first in melting ice, and then in boiling water, and marking upon the tube the two points at which the mercury stands, as represented here by F and B, two fixed or invariable points of reference are obtained, and the interval between them can be divided on the glass, or on a suitable scale attached to the glass, into any convenient number of parts to be called degrees. If follows farther, that by continuing the divisions to any extent both above and below the fixed points, a general scale of temperature would be obtained, with respect to which all thermometers made on the same principle would perfectly agree, although the size of the divisions on the tubes, would vary in the different instruments according to the comparative capacities of the bulb and tube.

713. The space between the two fixed points has been variously sub-divided, *i.e.*, there has been no agreement as to what should be understood by a degree of heat. Hence we have three different scales :—1st. The Centigrade, so named from its being divided into 100 spaces or degrees between freezing and boiling water. This was introduced by Celsius, a Swedish professor, in 1741. It is chiefly used in France and Northern Europe. 2nd. Réaumur's Thermometer, used in Spain. Réaumur, an eminent French philosopher, in 1731, divided the interval into eighty parts or degrees. This thermometer is but little employed, as the degrees are inconveniently large, and involve the use of fractions. 3rd. Fahrenheit, so named after its inventor, an ingenious experimental philosopher and Fellow of the Royal Society, born at Dantzic in 1686. In this scale, which was brought out about 1714, the space between boiling and freezing water is divided into 180 parts or degrees. Fahrenheit's thermometer is generally used in Britain, Holland, North America, and by English-speaking nations, and has many advantages over the other two. It is generally employed in manufactories, and for pharmaceutical processes. Its use is also sanctioned for fiscal purposes by Acts of Parliament.

The relations of these thermometers are of some importance, and it will be perceived from the different divisions of the scale that 9° of Fahrenheit are equal to 4° of Réaumur or 5° of Centigrade. Therefore, according to the rule of three, multiplying by nine and dividing by five or four, or the reverse, and adding or subtracting the 32° of Fahrenheit when required, gives the equivalent degree. It also follows from this relation, that the sum of the divisions of Centigrade and Réaumur ($100 + 80 = 180$) corresponds exactly to the divisions or degrees of Fahrenheit's scale. If, therefore, the degrees of C. are added to those of R., and 32° is added for temperatures above freezing, or deducted for temperatures below freezing, we obtain the degrees of Fahrenheit. Thus $21°\text{C.} + 17°\text{R.} + 32° = 70°$ Fahrenheit, and $18°\text{C.} + 14°\text{R.} - 32° = 0$, or zero of Fahrenheit. A real zero implies that point at which bodies lose all heat. From certain data it has been calculated to exist at about 460° below the zero of Fahrenheit (Ganot). This of course has not been verified by experiment.

In the Centigrade and Réaumur thermometers the freezing point of water is taken as zero, while Fahrenheit places his zero at 32 of his degrees below this point.* He made a mixture of snow and sal-ammoniac, and from this deduced his zero by the degree of cold produced.†

The zero thus taken by Fahrenheit is purely artificial, as with our present knowledge every zero must be. Graham has compared the scale of temperature to a chain extended both upwards and downwards beyond our sight. We fix upon a particular link and count upwards and downwards from that link, and not from the beginning of the chain. Fahrenheit preferred small to large links, and he placed his fixed point or zero so far below melting ice that all ordinary temperatures in habitable climates, are at once indicated by figures without rendering it necessary to resort to the + and − signs. In assuming melting ice as zero, the Centigrade and Réaumur thermometers require the constant introduction of these signs, leading to the risk of omissions and mistakes. Thus 14° F. stands for 18° below melting ice, but 14° C. may mean either 57° F. or 7° F. according to whether it is above or below melting ice. It is a great defect in these two instruments that, owing to this malposition of zero, there should be for common temperatures, a necessity for counting upwards and downwards. Further, the degrees are on much too large a scale for common use. Each degree of C. represents (1°·8) nearly 2° of F., and each degree of R. 2¼° of F. Hence slight changes of temperature are indicated on Fahrenheit's scale by whole degrees, when on the two other scales, fractions must be resorted to. The great inconvenience of this will be rendered obvious by the following comparative table showing the range of temperature at Eastbourne for the last seven days of January, according to Dr. Allnutt's observations. Mr. Symons has quoted this table to show how ill-adapted the Centigrade scale is for meteorological observations.

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* Experiments lately performed by Mr. Sorby show that the temperature at which water freezes may vary. In tubes of small diameter, water may be cooled to 23° without freezing, and in capillary tubes, it required to be cooled to 1°·4 in order to pass to the state of ice. This is close to the zero of Fahrenheit, and more than 30° below the freezing point of water, assumed as zero in the Centigrade and Réaumur scales.

† Fahrenheit found by experiment that 11,124 parts of mercury, raised from the degree of cold produced by a mixture of snow and sal-ammoniac, to the temperature of boiling water, increased in volume to 11,336 parts. The difference, 212, was taken by him to represent the entire range of the scale from his assumed zero to boiling water.

	Fahrenheit.		Centigrade.	
	Max.	Min.	Max.	Min.
Jan. 25	34°	30°	+1·1°	−1·1°
„ 26	30	23	−1·1	−5·0
„ 27	26	23	−3·3	−5·0
„ 28	35	27	+1·7	−2·8
„ 29	32	27	0·0	−2·8
„ 30	36	32	+2·2	0·0
„ 31	40	39	+4·4	+3·9

Typographical errors are frequently made in the + and − signs, and thus cause great confusion.*

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* The Centigrade thermometer has been described as the more scientific instrument, because it has a fixed and definite zero at melting ice. It may

714. The test of a good mercurial thermometer is that the tube should be of equal diameter throughout. A short column of mercury moved up and down should have the same exact length in all parts of the tube. No air should be left in it, or this will form a resistance to the free expansion of the mercury, and impair the accuracy of the instrument. In inverting a good thermometer, the mercurial column either fills the tube or breaks off at the bulb and falls to the end of the tube. This shows a perfect vacuum. If it does not fall completely, or breaks into several columns, the tube contains air. If it has been properly graduated,—when the bulb is placed in *melting ice* the mercury will fall to 32°, and remain fixed at this degree until all the ice is melted. Water may be cooled to 30°, and even lower, without freezing, but *melting ice* always represents a temperature of 32°. Out of eight thermometers the writer has found only two accurate in this respect. Many errors are made in recording temperature, owing to thermometers not having been thus tested and compared.

715. Although the direct expansion of any *solid* body by a moderate change of temperature, is so inconsiderable as to be with difficulty measured, M. Breguet, of Paris, ingeniously contrived, in 1823, a solid thermometer which makes it very evident. It consists of three thin layers of silver, gold, and platinum, the gold being in the centre. These are laminated into a delicate metallic ribbon which is twisted in the form of a spiral, and fixed at one end, the other end carrying a light copper needle, which can move round a horizontal dial graduated on the Centigrade scale. The different rates of expansion of the three metals by slight changes of temperature, are indicated by the movements of the

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be observed, however, that it is hardly scientific to use *mercury* for the measuring liquid, and to take for zero the solidifying point of *water*, which renders it necessary to count upwards and downwards for the ordinary range of temperature. Had the freezing point of mercury been selected as zero, there would have been some claim to scientific consistency in the arrangement, and + and − signs would have been thereby avoided. The freezing point of this metal is 72° F. or 40° C. below freezing water, for $40^\circ \times 1{\cdot}8^\circ = 72^\circ$. A thermometer thus constructed in F. degrees would have the melting point of ice at 72°, and boiling water at 252°. The objection to such a thermometer, is that it would make the scale inconveniently long for general use.

needle, the spiral either contracting or opening accordingly, as a result of unequal expansion between the silver and the platinum.

716. Air, although not used in ordinary thermometers, is well adapted to the formation of a *thermoscope*. It has a great extent of dilatation from a small increase of heat; it quickly receives impressions, and its dilatation is equal for equal increments of heat at all temperatures:—but atmospheric pressure cannot be excluded without at the same time confining the air and affecting its expansion. Professor Leslie, however, devised for particular purposes an air-thermometer, which he employed very usefully, calling it the *differential thermometer*. It consists of two bulbs, *a* and *b* (fig. 178), filled with air, and connected by a bent tube, *d c*, containing liquid—the instrument being hermetically sealed, so that the atmosphere cannot affect the air within. A greater heat in the bulb, *b*, than in *a*, as when *b* is touched by the warm hand or is exposed to the sun's rays, causes the liquid to descend in the tube, *d*, which has a graduated scale attached to it. We may observe that equal divisions or degrees marked on the scale of this thermometer, do not mark equal changes of temperature, for the increasing condensation and resistance of the air in the colder bulb, and the increasing height of the liquid column to be lifted, requires the force overcoming these to increase progressively.

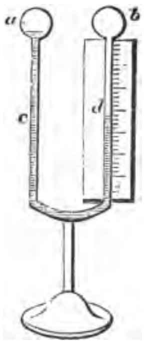

Fig. 178.

717. *Maximum* and *Minimum Thermometers.*—It is often desirable, as in garden hot-houses, to know how low the temperature has fallen during the night when no observer was present, and how high it has risen in the day. Both ends are attained by the use of Rutherford's twin-thermometers with horizontal tubes. The mercury in the tube of one pushes forward, as it advances with heat, a small piece of steel wire, and leaves it as a marker unmoved when it recedes again. The spirit or alcohol in the other, when contracting with cold, draws after it, by the mutual attraction, a small thread of coloured glass as marker, and then flows past this without moving it, when again expanding by heat.*

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* Mr. Negretti has constructed a thermometer to record temperature for any hour or series of hours on the principle of his deep-sea thermometer (see Art. 577, p. 391). The instrument is fixed on a clock, which can be set

Temperatures below that of freezing mercury are usually measured by a thermometric tube containing alcohol; and temperatures higher than that of boiling mercury are measured by the expansion of air or of metals, as above described, or by instruments called pyrometers, which are specially constructed for this purpose.

While "thermometer" implies the measurer of heat, "*pyrometer*"* implies the measurer of fire or temperatures above the range of the mercurial thermometer. These instruments depend for their action on the expansion of metals or of air. The results are not so accurate as those obtained within the range of the mercurial thermometer.

Formerly much importance was laid on the use of Wedgwood's pyrometer for high temperatures. He employed small cylinders of baked clay, which underwent contraction by heat, and the degree of contraction was measured by placing the cylinder, after heating it, in a groove in a brass plate, graduated. This groove was gradually reduced in width from the beginning of the scale, and the point which the cylinder reached and fitted, after it had been heated, was supposed to measure the degree of heat. This method has been laid aside as very inaccurate. There was no reliable standard with which it could be compared, and it was found that a long-continued low heat had the same effect on the clay-cylinder as a high temperature of short duration. The zero of this pyrometer was placed at a full red-heat, *i.e.*, about 1000° F., and it went up to 240°, corresponding to 32,277° F.

718. It is very interesting, while considering the vast number and importance of the phenomena produced by heat, to observe the degrees in the general scale of temperature at which certain changes take place. In the following table a selection of the facts connected with temperature has been made in some cases from actual observations, and in others from reliable authorities. They are all expressed on Fahrenheit's scale, the only thermometer used in this work.

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to any hour at which it may be desirable to record temperature. When the hand arrives at the hour, the thermometer is turned over by a simple clock movement; the thread of mercury breaks off and falls into a graduated tube where the degree can be read off.

* From the Greek, πῦρ, fire, and μέτρον, measure.

Table of facts connected with the influence of heat corresponding to certain temperatures.

Degrees below zero F.

Greatest artificial cold produced by nitrous oxide and bisulphide of carbon in vacuo (Natterer)	220°
Greatest cold from a bath of carbonic acid and ether in vacuo* (Faraday)	166°
Liquefied nitrous oxide freezes	150°
Liquefied sulphurous acid freezes	105°
Greatest natural cold (Siberia—Erman)	72°
Liquefied carbonic acid freezes	71°
Estimated temperature of planetary space (Fourier)	58°
Mercury freezes	39°
Mixture of equal parts of sal ammoniac and ice (Fahrenheit's zero)	0°

Degrees above zero F.

Air on the summit of Mont Blanc (15,781 feet) February, 1876, 3 P.M.	10°
Ice melts (zero of Centigrade and Réaumur)	32°
Animal heat—the human body (Blood-heat)	98°
Highest natural temperature observed in India	140°
Steamship engine-room, West Indies	154°
Alcohol boils	174°
Water boils	212°
Tin melts	442°
Bismuth melts	500°
Lead melts	612°
Mercury boils	650°
Black heat	700°
Zinc melts	773°
Antimony melts	900°
Red heat, visible in the dark	1000°
„ „ visible in daylight	1100°
Heat of a common fire	1141°
Bright red heat	1200°
Silver melts	1873°
Gold melts	2282°
French wrought iron melts	2732°
Hydrogen burnt in air	2739°
Cast iron melts	2786°
English wrought iron melts	2912°
Wind-furnace white heat	3280°
Combustion of hydrogen in oxygen	5478°

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* At this temperature Faraday observed that the alcohol used, became thick, like castor oil, and therefore ceased to measure lower degrees with

719. All solid bodies are considered to become visibly red or incandescent at or about 1000°, hence called a red heat, although observers are not agreed as to the precise temperature at which this takes place. A red heat visible in daylight, is, according to some authorities, 977°; others place it at 1000°, and others, again, at 1100°. This last statement is more in accordance with the writer's observations. Not only solid substances, but probably all *liquids*, not entirely volatile, become incandescent at the same temperature. Dr. Draper concludes from his experiments that, from common temperatures up to 977°, the rays emitted by a heated solid, are invisible (black heat). At this temperature they are red, and as the heat of the body increases continuously, other rays are added, increasing in refrangibility as the temperature rises.

A mass of gold, heated in glass or porcelain, will acquire a red heat at the same time as the glass or porcelain in which it is heated. Lead melted in a ladle may be made red-hot by continuing the heat above fusion. The red rays are emitted by the melted lead, and are plainly visible in the dark. The iron ladle, in which the metal is liquefied, will also appear red-hot at the same time. Above this temperature a solid body when heated, becomes orange-yellow, and ultimately white.

According to Bunsen, between a yellow-red, and white heat, the colours of intensely heated bodies pass through shades of blue to violet, while the white heat is the resultant of all the spectral colours emitted by the heated substance.

From what is said in the last and in preceding paragraphs, it is evident that the thermometer gives us very limited information with respect to heat: it merely indicates, in fact, what may be called the tension of heat in bodies, or the tendency of the heat to spread from them. Thus it does not enable us to discover that a pound of water takes thirty times as much heat to raise its temperature one degree, as a pound of mercury; nor does it indicate the heat of fluidity when bodies change their form.

"*Heat by its different relation to different substances has a powerful influence on their chemical combinations.*"

720. By observations made and recorded through past ages, man

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any accuracy. Hence this may be regarded as the lowest boundary of the thermometer which can be practically reached. All other liquids are solidified long before reaching this temperature.

has now come to know that the substances constituting the world around him, although appearing to differ in their nature almost to infinity, are yet all made up of a few simple elements variously combined; and he has discovered that the peculiar relations of these elements to heat, particularly their being unequally expanded by it, and their undergoing fusion and vaporization at different temperatures, furnish him with ready means of separating, combining, and new-modifying them to serve to him purposes of the highest utility. In many instances no chemical combination can take place without the application of heat, and it may be regarded in all cases as a necessary agent to the chemist. It either causes substances to combine or it separates those which are already combined. Many examples of this duplex operation have been already given in the preceding pages.

A piece of cold charcoal may lie in the air for centuries without change, but when heated to about 1000° it combines with one of the elements of air—oxygen, and produces the phenomenon of combustion, being at the same time entirely converted into an invisible gas (carbonic acid). In this case, according to modern views, the chemical force here represents motion, and the motion of chemical force is supposed to be converted into the motion of heat. Thus heat is evolved during combination, because the chemical force that gives rise to the combination, is always more or less converted into heat. In some cases a portion of the chemical force is converted into electricity, and in others into light.

To take another example. Sulphur and iron have no tendency to unite at ordinary temperatures; but if a bar of iron is made fully red hot and a stick of sulphur is applied to it, the two elements quickly disappear and melt into a new compound, sulphide of iron. A thick sheet of red-hot iron may thus be pierced by pressing against it a roll of sulphur. Sulphur manifests no tendency to combine with indiarubber in the cold; but if a sheet of this substance is dipped into melted sulphur at about 300°, a combination takes place, and a substance well known as vulcanized rubber is produced. The rubber retains from ten to sixteen per cent. of sulphur, and its properties are entirely changed. It is not affected by heat or cold; it is rendered much more elastic, and at the same time insoluble in all liquids which dissolve rubber. It does not soften and melt by heat like either of its two constituents, and it thus acquires a number of properties which render it far more serviceable in the arts and manufactures than the natural rubber. The heat required for vulcanization is remarkably well defined; if too low, there is no combination; if too high, a hard, dark compound like ebony is obtained.

721. There are some substances which do not require to be heated in order to effect combination. Mere contact at the lowest temperature is sufficient. Thus, when iodine is placed on a slice of phosphorus, both at a temperature of 32°, there is immediate combination of the two elements, with the production of a white heat and a most intense light. So when sodium wrapped in blotting paper is placed in a hole on a block of ice, it suddenly bursts into flame and produces a brilliant combustion. The illustrations, which might be produced, of the effect of heat in evolving chemical force or in producing chemical changes, are almost endless. In fact, it may be doubted whether any such changes can take place without the intervention of heat in some form. When dry iodide of nitrogen is allowed to fall through the air, it explodes. In this case the heat arising from the slight friction by contact with the particles of air is sufficient to separate the elements and produce an explosion like that caused by direct pressure or percussion. Powdered chlorate of potash, mixed with allotropic phosphorus, explodes with violence when mixed with a feather or a slip of paper. It is the heat arising from friction, however slight, which operates in these cases.

Heat can make and unmake chemical compounds of the same elements. The elements of water—hydrogen and oxygen—may remain mixed for centuries without combining at ordinary temperatures; but when a red heat is applied to the mixture, they instantly combine with explosion, and form liquid water. When a white-hot ball of platinum is introduced into this liquid water and a tube for collecting gases is placed over it, the oxygen and hydrogen are devolved, and may be collected as independent gases mixed in the proportions to form water. The heat required for their combination is 1000°, and for their separation at least 3000°.

722. The most wonderful effects of heat on the chemical and physical properties of bodies are, however, met with in some forms of *allotropy*.* Phosphorus, sulphur, and other substances are so altered by heat that they are no longer recognizable as the same elements. Common phosphorus is a white, waxy-looking substance, —combines with oxygen at all temperatures, and is luminous in the dark—highly inflammable at a low temperature (113°), soluble in sulphide of carbon and other liquids, and a deadly poison in small quantities. By simply exposing phosphorus for about forty hours to a heat of 464° in an atmosphere of carbonic acid or nitrogen, it undergoes a wonderful change, and appears to be converted into a new element. It is now of a dark red colour, hard and pulverizable. It requires a heat of 500° to ignite it. It is not luminous in the dark, and has no poisonous action on the body. It is not dissolved by any of the solvents of phosphorus. These extraordinary changes in properties—physical, chemical, and physiological—are due to the effect of heat. By carrying the temperature still higher, and distilling the red substance at a heat above 500°, it again resumes all the properties of common phosphorus, showing that the element is one and the same, and that it has really undergone no permanent change.

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* From the Greek, ἄλλος, other or different, and τρέπειν, to turn—signifying change of state.

723. No theory of heat offers any reasonable explanation of these remarkable facts. Motion or molecular vibration cannot account for such a change of properties as are here manifested. The late Professor Graham has justly observed that these phenomena appear "to require the admission of heat as a true constituent which can modify the properties of bodies very considerably; otherwise a great physical law must be abandoned, namely, that "no change of properties can occur without change of composition." But if heat be once admitted as a chemical constituent of bodies, then a solution of the present difficulties may be looked for, as nothing is more certain than that "a change in composition will account for any change in properties." Heat thus combined in definite proportions with bodies, and viewed as a constituent, must not be confounded with the specific heat of the same bodies, or their capacity for sensible heat, which may have no relation to their combined heat."

Heat is a necessary agent in the chemical changes which take place in organic substances in the processes of fermentation, putrefaction, and germination. Neither fermentation nor putrefaction will take place at a low temperature. They are completely arrested at the freezing point of water.

So, again, it is observed that every stage of the development and growth in living bodies is arrested by cold. On this principle the ova of salmon and other fish have been safely transported to Australia and New Zealand, and have there been developed by exposure to a proper degree of heat. In the middle of summer, recently-caught salmon packed in boxes with ice, is conveyed fresh from the most remote parts of Britain to the capital. During the warmest weather, flesh of any kind may be long preserved in an ice-house. Meat in a fresh state has thus been brought from North and South America. In Russia, Canada, and other northern countries, on the setting in of the winter frosts, when food for the cattle and poultry is with difficulty procured, the inhabitants kill their winter supply, and store up their frozen provender as in other countries men store what is salted or otherwise preserved.

A more striking illustration of this subject cannot be adduced than the fact that, in 1801, on the shore of Siberia, in a vast mass of ice, then accidentally broken and partially melted, the carcase of what has been called the antediluvian elephant or mammoth was found, perfectly preserved—an elephant differing in many respects from those now existing on the earth, but having a skeleton exactly similar to the fossil specimens now found buried in many countries. The carcase of this one, when exposed by the melting of the ice, was discovered by the hungry bears of the district, which were seen eagerly feeding on its flesh, as if it had died but recently, although it must have been of an era long antecedent to human records! After it had fallen from the ice to the sandy beach, and its tusks had been carried away for sale by a Tungusian fisherman, and much of its flesh had been devoured, a naturalist from St. Petersburgh, who visited it, found an ear still perfect, and its long hair and part of its upper lip, and an eye with the pupil, which had opened on the scenes of a much younger world! About thirty pounds' weight of its hair, which had been trodden into the sand by the bears, and part of the skin, were preserved, and are now distributed in different museums of natural curiosities. Portions of the skin with the hair upon it, are to be seen in the museums of Paris and of the London College of Surgeons.

724. The influence of *heat* is also strikingly manifested in the germination or growth of the seed, and under incubation in the development of the egg. Seeds buried deeply in the ground show no tendency to germinate. During the cold of winter, the vital energy of the seed is dormant. With the warmth of spring, germination commences, and we witness successively the growth of the plant from the seed, the rising of the sap, the new budding and unfolding of its leaves and blossoms, the ripening of its fruits, with the production of new seeds to perpetuate its kind. Then in the still more complex form of the egg, heat is equally essential. An egg which, if cold, would lie motionless until it was entirely decomposed, is converted, under the influence of heat, into a living being, which, in favourable circumstances, gradually attains maturity with form and faculties marvellous indeed, and among these, not the least is the power of reproducing eggs similar to that from which it sprang.

This metamorphosis is brought about by a heat of 104° applied to the egg, either by the warmth of the body of the hen or by artificial processes, during a period of three weeks; but heat alone cannot account for the phenomena which are here observed. If an egg is cooled to 32° or heated to 170°, it will no longer undergo the changes of incubation. In the former case the fluids are frozen; in the latter, the soluble is changed into insoluble albumen, and in both cases the vitality of the egg is utterly destroyed. Incubation, as the result of a heat of 104°, converts the soluble into insoluble albumen; but instead of its presenting an amorphous white mass, it appears in the form of feathers, beak, claws, cellular membrane, bone, blood, and of the soft organs generally, each presenting a wonderful construction or arrangement peculiar to itself. The chemist, by certain processes, may turn soluble into insoluble or coagulated albumen, but he cannot turn insoluble albumen into feathers, cellular membrane, bone, or muscular tissue. There is a force or energy required here which a regulated heat aids in developing, but which a higher or lower temperature will utterly destroy. This, which is called the vital force, distinguishes living from dead matter.

It is not, as some have asserted, chemical force which is here brought into play, for if the egg be shaken so that the albumen, yolk, and membranes are thoroughly mixed together, the heat of incubation will have no effect. Chemically speaking, the contents of the egg will be the same, and chemical force will act upon them as if they were entire, but no life will spring from the egg. So, again, in a chemical point of view, the albumen of the hen's egg does not differ from that of the egg of a duck, yet the heat of incubation converts the one into a web-footed bird, and the other into a bird which avoids the water.

Man, by arts of his invention, through COMBUSTION, FRICTION, *and* ELECTRICITY, *can produce heat at will, and he has thereby gradually acquired a great control over the elements around him.*

725. Probably there are no phenomena in nature more calculated to excite wonder and terror than fire or combustion. Great indeed must have been the surprise of the man who first witnessed the bursting into flame of two pieces of dry wood strongly rubbed against each other, a method still adopted by savage nations for procuring fire. Little could any one have then anticipated what has now come to pass, that this dread agent would in time, by human ingenuity, be rendered the most obedient and powerful assistant to man in all the labours of a high civilization. Under the domestic roof, fire is employed to prepare wholesome food for the people; in chemical laboratories and furnaces, it is used for separating metals from their ores, or melting together the sand and other ingredients which form glass; and, to say much in few words, fire, acting through the steam-engine, is now performing nearly all the kinds of mechanical labour which human hands had formerly to do, and many kinds of labour which, owing to their magnitude, the strength of men would never have attempted.

726. Singularly interesting, then, to philosophers, as in various uses the phenomena of combustion must always have appeared, one might have expected that its true nature would not long remain a mystery; but until the noble discoveries and reasonings of such men as Priestley, Lavoisier, Davy, and others, made barely a century ago, the conjectures offered on the subject had scarcely approached the truth. The common opinion was, that in every combustible substance there was present in close combination, a certain quantity of a something denominated *phlogiston*, which, on being disengaged or separated, became obvious to human sense as light and heat. For instance, the white oxide of zinc, called the flowers of zinc, into which the metal is changed by burning, was supposed to be the metal deprived of its phlogiston; and when, on this oxide being again heated in mixture with charcoal, the metal reappeared, it was supposed simply to have recovered phlogiston from the charcoal. The illustrious Lavoisier had the merit of clearly disproving this hypothesis, by showing that the flowers or powders obtained from metals by burning, were heavier than the pieces of metal from which they were produced, and by the exact weight of the oxygen gas which disappeared in the combustion; and he showed further, that in this and many other cases, combustion was merely the act of substances having a strong affinity or attraction for one another combining chemically; but he fell into an error of another kind by supposing that, in order to produce combustion, oxygen must always be one of the combining substances, and that the heat and light given out had in every case been previously latent in the oxygen.

727. When Sir Humphry Davy began his labours on this subject, than which there are, perhaps, on record few more interesting examples of scientific research, the existence and nature of oxygen had already been discovered by Priestley, the facts of latent heat by Black, and the important facts already referred to by Lavoisier. It was known also that bodies, when compressed, or by other means reduced in bulk, generally give out a part of their heat, as when air condensed under the piston of the match-syringe, lights tinder attached to the bottom of the piston, or when water and sulphuric acid, uniting into a compound of smaller volume than the separate ingredients, become very hot, or when water poured upon quicklime to slake it, and becoming solid with it, produces strong heat, and that in such cases the heat produced during chemical union, seemed to depend more upon the energy of the action which united the substances than upon the change of volume produced.

728. Out of these and other facts Davy drew satisfactory explanations. He concluded, first, that in any case, combustion is merely the appearance produced when substances having a still stronger attraction for each other than quicklime and water, for instance, are, with intense energy, combining chemically, so as to become heated to at least the degree of incandescence; and that during the phenomenon there is not, as was formerly supposed, something altogether consumed or destroyed, or something called *phlogiston* escaping, but that the substances concerned are only assuming a new form or arrangement of particles combining in perfect union. Thus if a piece of iron wire is strongly heated at one end, and then plunged into a jar of oxygen gas, it will instantly light up and burn as a most brilliant taper, and will gradually fall, in the form of oxidized drops or scales of iron, to the bottom of the vessel. During this process the quantity of oxygen in the jar will be diminished, but if the scales mentioned be collected, they will be found to weigh just as much more than the original iron wire expended, as there is of oxygen lost or combined with them. A chemist can separate this iron and oxygen, and exhibit them apart as before, without loss. Hence it follows that in all cases of combustion there is no loss of matter, but merely a change of state. The products may be invisible, but they nevertheless exist, and always admit of being collected and weighed. As an additional proof, the following experiments may be taken.

If a spirit-lamp is accurately balanced in a scale-pan, and the wick then ignited,—as the spirit burns there will be an apparent loss of matter, and the counterpoised scale will rapidly sink. If we hold over the burning wick, the open mouth of a gas jar, we may be able to prove by appropriate tests that the air of the jar is replaced by carbonic acid and aqueous vapour,—the latter being condensed as water on the inner cold surface of the glass. These products are formed at a high temperature, by the combustion of the spirit, or the oxidation of the carbon and hydrogen contained in the vapour of alcohol. If collected in a proper apparatus, the weight of these products would be equal to the weight of alcohol consumed.

If a piece of phosphorus is heated in a vessel of pure oxygen, all the oxygen disappears, but it is now solidified as phosphoric acid, and the increase in the weight of the phosphorus would represent exactly the amount of oxygen lost. In the burning of diamond or carbon in pure oxygen, there is no loss of gaseous matter, but the oxygen in this case is converted into gaseous carbonic acid; and it will be found, although unaltered in volume, to have acquired an increase in weight equal to the weight of the diamond or carbon consumed. Substances which undergo combustion in oxygen are rendered heavier; the weight of oxygen taken during combustion being always added to the original weight.

Combustion with and without Oxygen.

729. COMBUSTION, in its most extensive meaning, may be described as the result of intense chemical combination between two or more bodies, during which sensible light and heat are evolved.* All ordinary cases of combustion are dependent on the combination of *oxygen* with bodies; and the heat and light are dependent on the rapidity with which oxidation takes place, as well as on the amount of oxygen consumed.

The great combining element in nature, which is also the most universally distributed substance in the globe, is oxygen, of which the name is now familiar to the ears of even the unlearned. In a liquefied state it forms nearly four-fifths of the substance of water, and, as a gas, one-fifth part by weight of the atmosphere, being on the latter account present wherever man can live, and ready to unite with any matter exposed to it at the necessary temperature. Now, of substances burning in air, those which are aëriform, as coal gas, or which, on being heated, are rendered aëriform before the union takes place, as oil or wax when much heated, assume the appearance of flame, which means that the aëriform particles previously invisible are raised to the incandescent temperature; but when the mass of the substance combining with the oxygen remains solid, while its particles are gradually lifted away by the oxygen acting only at the surface, it appears, during the whole time, only as a red-hot stone. The latter is the case with diamond, charcoal, coke, Welsh stone-coal, and all substances which evolve no vapour when heated. In the case of wood, common coal, &c., a greater or less portion of the inflammable matter is, by the heat of combustion, converted into vapour, and so produces the beautiful appearance of *flame.*

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* The combination of oxygen with certain metals, when not attended with sensible light and heat, is called simply oxidation. It is only when these are vividly evolved that the term combustion is strictly applicable. Potassium is oxidized at 32°, and iron at ordinary temperatures. The combination takes place in both cases without the evolution of sensible light and heat

730. Most substances require to be heated before they undergo combustion in air, and some, like the diamond, will only burn at a very high temperature when heated in pure oxygen. Common phosphorus does not enter into combustion in oxygen below a temperature of 80°, or in air below 113°, while in the allotropic state (p. 510, Art. 722) it requires to be heated to 500° before it will take fire and burn. Oxygen, as it exists in air, shows no tendency to combine with sulphur below 500°, with hydrogen below 600°, with carbon below a red heat, 1000°, or with zinc below its vaporizing point, 1900°. This want of action at low temperatures appears to depend less on the absence of "affinity" between oxygen and the substance, than on the effect of cohesive attraction on the particles of the substance exposed to the gas. Thus iron and lead in their ordinary state will not burn in air; but when the particles of these metals are reduced to a fine state of division, they take fire and burn on coming in contact with air, like larger masses which have been heated to redness.

This observation leads to another. If the atmosphere consisted only of oxygen, all combustible substances once ignited, would continue to burn until they were entirely consumed, or all the oxygen had disappeared. A conflagration once raised could never be extinguished. We see, therefore, that on the one hand, by the cohesive force in solids, and on the other by the diluting effects of the large proportion of nitrogen in the atmosphere, the results of fire as manifested by combustion are brought within controllable bounds.

On the circumstance that combustible bodies require to have a certain preparatory warmth before beginning rapidly to combine with oxygen, depend many important facts in nature and art. Hence the safety with which combustibles may be exposed at ordinary temperatures to the contact of atmospheric air. Were it otherwise, any kind of coal or wood, &c., in the moment of being exposed to the air would catch fire, just as happens to phosphuretted hydrogen gas when allowed to rise into the atmosphere.

731. The physical condition of the substance also makes a difference. Wood charcoal in large pieces will not be heated by exposure to air so as to become ignited; but it has been observed that recently-prepared charcoal in a fine state of division rapidly absorbs the oxygen of air, and becomes intensely heated. M. Aubert has found it to acquire a temperature of 350°, and it has been known under these circumstances to undergo spontaneous combustion. A slice of phosphorus will appear luminous in the air, but it will not take fire and burn below a temperature of 113°. If the phosphorus is dissolved in sulphide of carbon, and the solution is poured on thin paper, the phosphorus is left, by evaporation of the liquid, in very minute particles on the surface of the paper. The oxygen of the air heats these small particles sufficiently to cause combustion, and the whole bursts into a flame of burning phosphorus. The *spontaneous combustion* of coal does not arise in the first instance from the carbon of the coal uniting to oxygen, but from the heat produced under the slow decomposition of mineral pyrites by the agency of water. This alone raises the temperature of the mass sufficiently to cause the combustion of the coal in air. Many ships have been destroyed at sea owing to this spontaneous heating of the coals, and a Committee of the House of Commons has been recently appointed to examine into the causes, and suggest, if possible, methods of prevention. Stacks of newly-cut hay sometimes, by a species of fermentation, undergo such intense heating as to take fire spontaneously.

732. If a fire or flame be very small, the rapid absorption of heat from it by cold bodies around, so lowers the temperature of the substance that the combustion is soon extinguished. Thus a common coal fire, if it be not watched, and the remaining fuel be not occasionally gathered together, to reduce the surface of wasteful radiation, will be extinguished long before the whole fuel is consumed; but not so with lighted wood or paper, which substances burn more readily than coal. The Welsh stone-coal can be made to burn steadily only when in large masses, or when mixed with a more inflammable coal or other fuel, or when surrounded by fire-brick, which retains the heat well, or when fed by air already heated. The manufacture of iron has lately been improved, and much cheapened, by causing the air which feeds the furnace to be warmed by passing through metal tubes heated in another fire. This proceeding constitutes what is called the *hot-blast.*

733. The phenomena of combustion are equally seen in some of the combinations of chlorine, bromine, and sulphur with bodies. When phosphorus is introduced into a jar of chlorine it speedily melts, takes fire, and burns with a pale yellowish flame, forming chloride of phosphorus. If thin leaves of Dutch metal are introduced into chlorine, or into the vapour of sulphur, they burn with out flame, producing a full red heat, and forming chloride or sulphide of copper. These experiments clearly show that oxygen is not in all cases necessary to combustion, and that the phenomena which attend it cannot be regarded as dependent upon any peculiar principle or form of matter; they must be considered as a general result of intense chemical union. Each substance, in fact, has its own special properties in reference to combustion. Sulphur will not burn in chlorine, and to cause it to burn in oxygen it must be heated to a very high temperature (500°). Copper will not burn in oxygen gas, but it will burn at a low temperature in chlorine, and at a high temperature in sulphur.

Ignition.—Incandescence.

734. Combustion always implies chemical action : either the heat of the combining bodies or that which results from their combination is set free, and with this a proportionate quantity of light; but a body may evolve heat and light without undergoing combustion or any chemical change. Thus a platinum wire, some fibres of asbestos, or a piece of lime, exposed to the strong heat of an invisible flame—*e.g.*, of oxygen and hydrogen—may be heated to whiteness, evolving both heat and light of surprising intensity. To this state the term *ignition*, or incandescence, is applied. The body evolves light as a result of its being intensely heated, without its molecules being materially altered in their physical or chemical relations. It is not fused at the temperature to which it is exposed ; and the greater the amount of heat which it is capable of receiving without a change of its physical condition, the more intense the light which it emits. An ignited body, therefore, serves as a temporary storehouse of heat and light. The vacuum-light furnishes a remarkable instance of the results of ignition. The charcoal points, being the terminal poles of a powerful battery, are enclosed in a glass vessel in which a vacuum has been artificially produced. The light issues in great splendour, as the result of the ignition or incandescence of minute particles of charcoal carried between the poles, but the charcoal itself undergoes no combustion. When platinum points are used, portions of that metal are volatilized and are so heated as to give out the intense violet blue light which characterizes the spark. Even *gases* attenuated to the highest degree—in fact, almost converted into a vacuum by the air-pump—may be rendered incandescent by the discharge of the spark from Ruhmkorff's coil.* In an absolute vacuum no discharge passes, as electrical conduction necessarily requires the presence of matter; but Mr. Gassiot's experiments have proved, that what has been hitherto regarded as a vacuum, is space filled with highly attenuated matter capable of being made incandescent by the electric discharge. The vivid luminosity and the varied colour of forked lightning are probably dependent on the incandescence of the gaseous and vaporous constituents of the atmosphere, modified by the density of the stratum in which the electric discharge takes place.

It is found that the greater number of *metals* may be converted into vapour, and that these vapours, when rendered incandescent by the current, emit a light varying in colour for each metal. For the purpose of obtaining the metals in a volatile state, the platinum poles are moistened with the respective solutions. M. Faye found that zinc gave a blue colour in strata or bands; antimony, a lilac colour; mercury, a pale blue; cadmium, an intense green; arsenic, a magnificent lilac; and bismuth, a variety of colours, undergoing rapid changes. ('Cosmos,' Sept. 20, 1861, p. 321.) It has been further proved that these coloured flames and incandescent vapours present coloured spectra of differently refrangible rays, in some instances characteristic of the substance.

Supporters of Combustion and Combustibles.

735. Although oxygen, chlorine, and bromine give rise to the phenomena of combustion with other bodies, they cannot be made to combine with each other, so as to evolve light and heat; and hence they are said to be incombustible. In ordinary language they are called *supporters* of *combustion*, while the bodies to which they unite have been called *combustibles.* It is, however, generally admitted that the phenomena of combustion are dependent on the union of the two bodies; and that the so-called supporter is consumed as well as the combustible, and aids in furnishing the light and heat. Thus, copper and sulphur at a high temperature combine with combustion. Which is the supporter, and which the combustible? Both must be regarded as combustible substances, for copper burns in chlorine, and sulphur burns in oxygen. Whether we put phosphorus into the vapour of chlorine, or chlorine into the vapour of phosphorus, the same kind of combustion equally ensues, and the products are similar. During the combustion of phosphorus in oxygen, the intense and sudden burst of light which appears after the phosphorus has entered into the boiling state, arises from the diffusion of its vapour throughout the whole of the oxygen of the vessel, so that there is a combustion of both at every point of contact. Up to this time the light and heat may have appeared to proceed from the solid phosphorus only; but it will now be observed to issue equally from all parts of the vessel containing the oxygen. The oxygen is here as much a combustible as the phosphorus. In fact, the term "combustible" is relative and arbitrary; that body which is for the time in larger quantity, or in the gaseous state, is called the "supporter." Coal-gas burns in oxygen or air only where it can unite with oxygen, and it is therefore called a combustible gas. If we kindle a jet of coal-gas issuing from a bladder, and cause the flame to be projected into a bell-glass of oxygen, it will burn brilliantly. If we fill another bell-glass with coal-gas, ignite it at the mouth, and project into it through the flame, a jet of oxygen, this gas will appear to burn, and in fact does burn, in a jet precisely like the jet of coal-gas, and it will be found to give out the same amount of light and heat, and to give rise to similar products. The oxygen and coal-gas burn only where they meet each other at a high temperature. The oxygen burns in an atmosphere of coal-gas just as certainly as the coal-gas burns in an atmosphere of oxygen. This may be further illustrated by an experiment with an ordinary argand gas-burner. A long chimney-glass should be placed over the burner, and all access of air from below cut off by a cork and a disc of card. If after allowing the coal-gas to issue for a few minutes in order to remove the air, it is ignited at the top of the chimney-glass, a jet of oxygen may be safely propelled downwards through the gas-flame, and the oxygen will appear to burn in the glass cylinder containing the coal-gas. These facts show that combustion is really a reciprocal phenomenon, each body burning, or, in chemical language, combining with the other body, and during this combination evolving light and heat. The terms combustible and supporter of combustion are, however, convenient for use, provided we understand by them that each substance shares in the process, and that neither is, strictly speaking, passive.

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* See Section on Electricity.

Heat and Light of Combustion.

736. The results of experiments by Despretz show that the heat of combustion in some cases depends, not so much upon the quantity of combustible, as upon the weight of oxygen, consumed. A pound of oxygen, in combining respectively with hydrogen, charcoal, alcohol, and ether, evolved in each case very nearly the same quantity of heat, each raising 29 lbs. of water from 32° to 212°. But with respect to the comparative heating powers of equal weights of different combustibles, Despretz obtained the following results :—

	Pounds of Water.		
1 pound of hydrogen raised . . .	236	from 32°	to 212°
„ oil, wax	90	„	„
„ ether	80	„	„
„ pure charcoal . . .	78	„	„
„ common wood charcoal	75	„	„
„ alcohol	68	„	„
„ bituminous coal . . .	60	„	„
„ baked wood	36	„	„
„ wood holding 20 per cent. of water . .	27	„	„
„ turf (peat) . . 25 to	30	„	„

This table indicates, not the absolute amount of heat evolved, but the relative heating power of fuels burnt under similar conditions ; and it further appears to show that, provided the same weight of oxygen be consumed, whatever may be the nature of the fuel, the same amount of *heat* will be evolved. In order to produce an intense heat, therefore, the object is not so much to consume the fuel, as to consume the maximum of oxygen with a minimum of fuel. The heating power of the blowpipe and of the blast-furnace, especially of the *hot* blast (to counteract the cooling effect of the nitrogen associated with oxygen in the air), will now be intelligible on chemical principles. It is not, however, strictly true that the same weight of oxygen always produces by combustion the same amount of heat. Other experiments performed by Despretz have shown that a pound of oxygen, in combining with iron, tin, and zinc, could heat nearly twice as much water to the same temperature as that which in his table he assigns to hydrogen, carbon, alcohol, and ether; hence, in reference to these metals, oxygen alone cannot be concerned in its production. So with regard to phosphorus: if this substance is burnt slowly, to produce phosphorous acid, a pound of oxygen in combining with it, evolves the same amount of heat as that assigned to carbon and hydrogen; but if the combustion is so intense as to produce phosphoric acid, then the heat evolved is twice as great, resembling that which is given out in the combustion of iron, tin, and zinc. There is another fact which shows that the rule regarding the evolution of heat is not so simple as Despretz had supposed; namely, that when carbon is already combined, as in carbonic oxide, the amount of heat evolved during its combustion and conversion into carbonic acid, is nearly equal to that which would be evolved by the carbon in a separate state, although the latter would require twice the amount of oxygen to convert it into the same product (carbonic acid). (Kane's Elements of Chemistry,' p. 244.) The later researches of Professor Andrews and other chemists have shown that the quantity of heat evolved as a result of the chemical combination of bodies is definite, and that it has a specific relation to the combining number of each substance. With a proper supply of oxygen, or air, a given weight of the substance always produces the same amount of heat.

737. All our ordinary sources of light and heat for domestic and manufacturing purposes are dependent on the combustion of hydrogen and carbon which are found associated in variable proportions in coal, wood, and oil. The following table shows that, according to the experiments of Despretz, hydrogen and carbon, weight for weight, consume the largest amount of oxygen in undergoing perfect combustion; and that hydrogen, in uniting to oxygen, has more than three times the heating power of carbon:—

	Pounds of Oxygen.		Pounds of Air.	Prop. of Combustible to Oxygen.
1 pound of hydrogen takes .	8	or	40	1 : 8
6 pounds of carbon take . .	16	or	80	1 : 2·6

Hence, by reason of this enormous consumption of oxygen in proportion to the weight of material burned, hydrogen, and bodies containing it, evolve the greatest amount of heat. Hence, also, in the oxy-hydrogen blowpipe we have one of the highest sources of heat at present known; and as an indirect result of the absorption of this heat by the infusible substance, lime, we obtain a light which rivals that of the sun in intensity and chemical power. Lately, by the construction of a close furnace of lime, and the use of the oxy-hydrogen flame, MM. Deville and Debray have not only been able to volatilize many of the supposed fixed impurities in commercial platinum; but with about 43 cubic feet of oxygen, they have succeeded in melting 25 pounds of platinum in less than three quarters of an hour, and casting it into an ingot in a coke mould. All metals are melted, and many are entirely dissipated in vapour, by the intense heat produced under these circumstances. The lime itself is unaltered by the heat, and acts as a powerful non-conductor, even when not more than an inch in thickness. Lime and magnesia appear hitherto to have resisted fusion, or volatilization as oxides.

In reference to combustion, the improvements made in the use of gas as a source of heat have depended on the admixture of air, or on the free supply of air, by a variety of arrangements; and, in the construction of all furnaces, the adoption of this principle leads to an economy of fuel, the prevention of smoke, and the production of the largest amount of heat. The smokeless flame of a Bunsen's burner, derived from the combustion of mixed air and gas, gives but little light, with an intense heat.

Nature of Flame.

738. It has been elsewhere stated that flame is nothing more than the combustion of volatile or gaseous matter emanating from the heated solid and extending to a certain distance above it. Those bodies only burn with flame which, at the usual burning temperature, are capable of assuming the vaporous or gaseous state. Charcoal and iron burn without flame; their particles are not volatile at the temperature at which they burn. Phosphorus and zinc, on the other hand, are volatile bodies, and therefore burn with flame. Small particles of each substance are carried up in vapour, are rendered incandescent by the heat of combustion, and burn wherever they meet with the atmospheric oxygen: the more volatile the substance, the greater the amount of flame.

739. The flame of a candle or of gas is hollow,—a fact which may be proved by numerous experiments. If a piece of metallic wire gauze be depressed over a flame, this will be seen to form a ring or circle of red heat in the metal, dark in the centre, and luminous only at the circumference, where the gaseous particles meet with oxygen. The inflammable matter traverses the meshes of the gauze, but is so cooled by the conducting power of the metal that it ceases to burn above. (See Art. 607.) A piece of stiff paper, suddenly depressed on a spirit-flame to about its centre, presents a carbonized ring corresponding to the circularity of the flame. If a thin platinum-wire be stretched across a wide flame of alcohol, it will be heated only at the two points, corresponding to the circumference, where combustion is going on.

740. By allowing a jet of gas to issue from a glass-cylinder in the manner already described, a variety of experiments may be performed to show the hollowness of flame and the comparatively low temperature of the gas or vapour in the interior. An iron wire laid across the cylinder becomes red-hot only at the edges of the chimney-glass. A deal splint will take fire and burn at these points, but be unchanged in the centre. A lighted wax taper fixed on wire, introduced suddenly through the sheet of flame is extinguished in the interior. Gunpowder introduced in a ladle may be held in the inner space within the flame for a long time, and even withdrawn, without exploding. Gun-cotton will not explode under these circumstances if introduced at the end of a copper wire while the coal-gas is freely issuing from the chimney-glass, and the jet is not kindled until after its introduction. That the inner portion of every cone of flame consists of unburnt gas, or combustible vapour comparatively cool, may also be proved by placing within it, the open end of a glass tube, supported by wire, and applying a lighted taper at the other end of the tube which projects out of the flame. The unburnt gas or vapour will be conducted off by the tube, and may be kindled at the end of it, as from an ordinary jet. Thus, then, all inflammable gases and vapours, when unmixed with oxygen, have only a surface combustion, which is defined by the access of oxygen and its contact with the heated gas or vapour. It is different when the burning gas or vapour has been previously mixed with oxygen. Under these circumstances the flame is *solid*, *i.e.*, combustion is taking place throughout the whole of the mixed gases. Thus, in burning a jet of mixed oxygen and hydrogen, the whole cone of flame is matter in a state of combustion, and the heat is proportionably more intense.

741. Flame in all cases consists of matter ignited to a very high temperature. Sir H. Davy assigned a white heat (3280°) to ordinary flame. Bunsen, by a series of ingenious experiments, has arrived at the following results respecting the temperature of flames ('Phil. Mag.' Aug. 1860, p. 92). The temperatures assigned by him are those of the Centigrade thermometer, of which 5° are equal to 9° of Fahrenheit, plus 32° for the difference of the zero :—

Sulphur flame. . .	1820°	Carbonic oxide flame .	3042°
Sulphide carbon . .	2195°	Hydrogen flame (in air)	3259°
Coal-gas flame . .	2350°	Oxy-hydrogen flame .	8061°

The heat of the electric current far surpasses all these temperatures, and is at present undeterminable in its degree, by any known process.

Products of Combustion.

742. In ordinary combustion the consumption of oxygen is very large, and the vitiation of the air in an enclosed space by the diffusion of the products, very rapid. The writer has found that a common candle, with a thick wick, requires for conduction two gallons of air per minute. This represents 110 cubic inches of oxygen. It will be seen from this how rapidly the air is consumed by the burning of candles or lamps in the deep shafts of unventilated mines. The respiration of an adult consumes the air in like proportion.

The consumption of air by the burning of gas, is even larger and more rapid. A cubic foot of coal-gas requires three cubic feet of oxygen for its combustion. This is equivalent to fifteen cubic feet, or ninety-four gallons of air. An ordinary gas-burner will consume this quantity in a quarter of an hour. All the oxygen is not removed under these circumstances, but the air is rendered unfitted for the purposes of breathing or for further combustion.

Heating or warming by gas is, therefore, highly injurious, unless there is a free supply of air and provision is made for carrying off the resulting products.

The products of ordinary combustion in oxygen are chiefly *carbonic* acid and *water*. These are quite unfitted to sustain combustion, and unless removed as they are produced, they speedily arrest the process. In the burning of coal or coal-gas, the production of sulphurous and nitric acids is an additional source of noxious impurity. A burning candle or a jet of coal-gas is immediately extinguished in carbonic acid, but carbonic acid will serve as a medium for the combustion of certain substances when heated to a high temperature. Thus the metal sodium burns with great brilliancy in a current of pure carbonic acid, the gas becoming in this case as much a supporter of combustion as oxygen itself. These exceptional conditions, of course, admit of explanation on chemical principles. They show that there is no real distinction between a product and a supporter of combustion.

743. In *combustion* in air, the oxygen alone is consumed, the nitrogen is set free, and mixes with the carbonic acid produced at the expense of the oxygen. Air is therefore rapidly contaminated by this process; and in a confined space, the nitrogen and carbonic acid, as a result of the heat evolved, accumulate in the upper part of the vessel or apartment. Neither of these gases is respirable, and neither will support ordinary combustion. The following experiments will illustrate the deterioration of air under these circumstances. Fix three wax tapers to a stout wire placed upright, and about three feet in height, so that one is at the upper part, one at the lower, and the third in the middle. Light the tapers, and invert over them a tall stoppered shade, leaving a slight space for the entrance of air below. The rapid accumulation of deoxidized air (nitrogen) and carbonic acid in the upper part of the shade, will be indicated by the early extinction of the upper and middle tapers, while the lower one will continue to burn. If, when the lower taper is burning dimly from impurity of the air, the stopper is removed from the shade, a current of air is immediately set up, the gaseous products of combustion are carried off, and the lower taper will burn with a still brighter flame. This experiment establishes the necessity for a rapid removal of the products of combustion, and the results are equally applicable to the contamination of air by the respiration of animals.

744. When combustion takes place in rarefied air, as when a candle is placed under a receiver from which the air has been partially removed by the air-pump, the flame is elongated, becomes less luminous, and is soon extinguished. According to observations made by Dr. Frankland, in 1859, on the summit of Mont Blanc, it appears that at this elevation the amount of combustible consumed is as great as at the level of the sea, although the light emitted by a burning candle is considerably less.

745. But combustion may go on at one part of a closed room while the burning substance will be extinguished in another part of the same room. Fix in the stoppered aperture of a bell jar, by means of a closely-fitting cork, a glass tube, about an inch in diameter. The tube should rise several inches above the level of the jar, and should reach on the inside to within two inches of its base. Mount in a plate two pieces of wax taper, one sufficiently tall to reach nearly to the top of the jar when placed over it, the other so short, that when ignited, the point of the flame only, will be enclosed by the open end of the glass tube fixed in the jar. Light the tapers and invert the jar over them, not pressing it down closely at the base. The tube should be so adjusted to the short taper, as to act like a chimney to it, care being taken that it is not touched by the flame. In a short time, if the cork is well fitted, the tall taper will be extinguished, but the short taper will continue to burn. In the one case, the products of combustion are not carried off, in the other they are, and the supply of air is continually renewed. As a proof of this, if we hold over the chimney-tube a small gas-jar, the deposition of water on the glass will be apparent, and after a time, the presence of carbonic acid may be proved by pouring lime-water into the jar. (The production of carbonate of lime will be indicated by a milky appearance of the lime-water.) The proper *ventilation* of apartments, implies a strict adjustment of the supply of pure air for combustion and respiration, and a provision for the complete removal of the products as they are formed.

746. The subjoined engraving (fig. 179) will serve as an illustration of these principles. Two tall chimney-glasses, A B, are fitted closely to holes in the top of a small box, which is made quite air-tight, so that no air can enter or escape except by the chimney-glasses. A short piece of wax taper is lighted and placed in the glass, B. It burns readily by reason of the air derived from the box, and continuously supplied by a descending current through the glass, A. The consumed air escapes by B, as indicated by the arrow. If A is closed with a glass plate, the taper in B will be soon extinguished owing to the non-supply of air. If B is closed in a similar manner,—the taper is also extinguished by reason of the non-escape of the products of combustion, carbonic acid, and aqueous vapour,—the carbonic acid collected in B rapidly

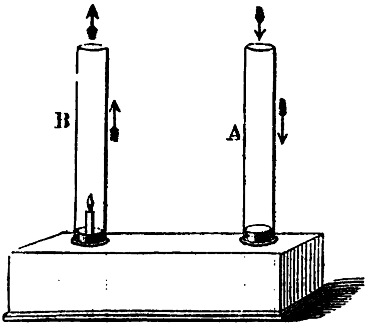

Fig. 179.

arresting combustion. Nitre-paper in smoky combustion, brought near the top of A, indicates the current downwards by the course of the smoke, while when placed over B the smoke is carried upwards. By breathing gently into the glass, A, or bringing near to it a jar containing carbonic acid, the taper will be extinguished. On the other hand, a jar of oxygen brought near to it will cause the taper to burn more brightly.

The figure serves, also, to illustrate the method by which mines are ventilated. B represents what is called the upcast shaft, in which a fire is kept constantly burning, while A corresponds to the downcast shaft, which serves to supply fresh air to all the workings.

Combustion by Oxygen salts.—Deflagration.

747. It is not, in all cases, necessary that oxygen should be *free*, or in the gaseous state, in order that combustion should take place. Saline compounds which contain oxygen, such as the nitrates and chlorates, when mixed with combustible substances, such as sulphur and charcoal, give rise to combustion of the most intense kind, often amounting by its suddenness to explosion. Nitre, charcoal, and sulphur are the constituents of gunpowder. When mixed in certain proportions and heated to about 500°, the solid compound is suddenly converted into gaseous and vaporous matter, expanding into two thousand times its volume and rending and destroying all substances with which it is in contact. Gun-cotton presents another illustration. The fibre of cotton is here incorporated with the elements of nitrous acid, and the oxygen, which forms a large proportion of them, is sufficient to cause the sudden conversion of the whole of the carbon and hydrogen in the cotton, into water and carbonic acid.

Finely powdered charcoal, mixed with an equal portion of powdered nitrate or chlorate of potash, burns, when heated, with great violence, giving rise to the phenomena of *deflagration.* A mixture of twenty-eight parts of ferrocyanide of potassium, twenty-three parts of white sugar, and forty-nine parts of chlorate of potash, is known under the name of "*white gunpowder.*" In combustion it produces a large amount of gaseous matter, consisting of nitrogen, carbonic acid, carbonic oxide, and aqueous vapour. It is a dangerous compound to prepare or even to preserve. This composition, when dry, is exploded by friction or percussion, by heat, or by the contact of concentrated sulphuric acid.

748. *Combustion of vapours.—Slow combustion.*—When atmospheric air, mixed with certain inflammable vapours, as ether, is allowed to be in contact with a moderately heated body, a very slow union may take place without flame. This phenomenon has been called invisible combustion. It is remarkably exemplified on placing a small coil of platinum wire, moderately heated, in such a mixture : the combination of the vapour with air then goes on in the immediate vicinity of the hot wire, with sufficient disengagement of heat to maintain the wire in a feebly luminous state, at a low red heat. Thus the vapour always arising at a common temperature from the open mouth of a glass containing ether, if made to pass through a red-hot coil of platinum wire, will, while combining with the oxygen of the air, give out heat enough to keep the wire red-hot so long as the vapour lasts. A ball of finely divided platinum (spongy platinum), mixed with clay and dried, has a similar property. If heated to redness and then placed on the wick of a spirit lamp, it will remain glowing, so long as any vapour of spirit is evolved. This has been called Sir H. Davy's *aphlogistic lamp.* All liquids which evolve vapour and do not block up the pores of the platinum, operate in a similar manner. Even solids which emit vapour, undergo this kind of combustion. Thus a platinum ball heated and placed on a block of camphor continues to glow, and causes a slow combustion and volatilization of the camphor.

"*Fuel.*"

749. HEAT being, in the sense already explained, the life of the universe, and man having command over nature chiefly by his power of controlling heat, as a result of combustion, it is of interest to inquire what substances can be employed economically as *fuel* for producing and maintaining artificial heat. The all-important substance, oxygen, forms part of our atmosphere, and therefore penetrates and is present wherever man can breathe, ready at once for his service. Then for the purpose of combining with the oxygen, there are chiefly two other substances also very abundant in nature—namely, carbon and hydrogen, which are the great materials of all things of vegetable origin, as trees, bushes, grasses, &c., and therefore of coal-beds, many of which are evidently the condensed remains of forests which existed in remote past time. Carbon is found nearly alone in the hard coal called anthracite, or stone-coal, but it is united with a large proportion of hydrogen in caking or bituminous coal, and in wood, resins, tallow, and oils, including the rock oils of Canada and Pennsylvania. The mixture of inflammable gases known under the name of coal-gas, and now universally employed for the purpose of illumination, is chiefly hydrogen in combination with variable proportions of carbon. All bodies which burn with flame give out gas or vapour while in the act of combustion. The stones, earths, water, &c., seen at the surface of this globe, are already saturated combinations of other substances with oxygen, and are, therefore, not in a state to produce combustion by further combination. Carbon and hydrogen, by various processes of vegetable and animal life, are always in numberless situations being combined and accumulated, so as to become fit for fuel.

750. Under solar light, and by the chemical force emanating from the sun, plants are enabled to decompose carbonic acid and aqueous vapour, the products of respiration and combustion. They appropriate the carbon and the hydrogen in their tissues and liberate the oxygen which becomes diffused through the atmosphere. The plants decay, and in the course of ages are transformed by subterranean heat and pressure into coal. Hence in accordance with this theory, by the combustion of coal, we are actually converting into heat the chemical force that emanated centuries ago from the sun.

The name " fuel " has been given to the substances which combine with oxygen, and not to the oxygen itself, because the former, being obvious to the senses as solids and liquids, had attracted notice as producers of combustion, long before the existence of the aëriform agent, oxygen, was even suspected.

Oils, fat, wax, &c., from becoming gaseous in their combustion, exhibit the appearance of flame, as already explained, and hence are used chiefly for the purpose of giving light ; while wood and coal are more frequently used for mere heating. But the chemist's oil-lamp and gas-furnace, by which he distils, evaporates, and melts substances, and the gas-apparatus of a kitchen, prove that it is chiefly the greater expense of gaseous fuel which has limited it so much to the purpose of light-giving.

Wood was the common fuel of the early world when coal-mines were not yet known, and still in many countries, it is so abundant as to be the cheapest fuel. Charcoal is the name given to what remains of wood after it has been heated in a close place out of contact of air, during which operation the hydrogen and other volatile ingredients are driven away in the form of vapour. Charcoal is nearly pure carbon. Coke, again, is the charcoal obtained by a similar process from coal. Wood, common coal, and oil, if much heated in the open air, burn or combine with the oxygen of the air ; but if heated however much in a vessel or a place which excludes air, they do not burn, but merely give out their more volatile parts in the form of transparent inflammable gas to be conveyed through tubes and burned elsewhere.

751. *Coal and Coke compared as fuel.*—The more completely a coal is capable of being burnt within a furnace or grate, the better is it adapted for the purpose of heating. Long furnaces stoked with coal in front, cause a most perfect combustion of the fuel, for the oily and tarry vapours which are thrown off, are entirely oxidized and consumed by passing over the red-hot fuel before reaching the flue of the chimney. Fires in ordinary grates should be treated on the same principle. No more coal should be put on at one time than the heat of the fire is adequate to consume ; otherwise a distillation goes on which fouls the chimney and wastes the heating power of the fuel. The greater the amount of volatilizable matter the fuel contains, the less suitable is it for heating, and the greater the quantity of smoke and soot, produced. The ash, or mineral portion, of the best coals rarely exceeds two per cent. Some inland coals yield ten or twelve per cent.

The volatile products which escape from burning coal and pass into the flue are—aqueous vapour in large proportion, some carbonic acid, hydrocarbonic vapours (paraffine), and ammonia, with sulphuretted hydrogen. The hydrocarbon vapours, if completely burnt, are capable of giving much heat, but as there is not sufficient oxygen to combine with all the hydrogen and carbon, the oxygen takes the hydrogen by preference to form watery vapour, while the unburnt carbon is deposited as soot.

Coals which give off a large quantity of oily and volatile products are better fitted for the manufacture of gas than for heating purposes.

Coke, containing from 80 to 90 per cent. of carbon is well fitted for heating purposes in grates with a good draught of air. It contains but little volatile matter and deposits no soot, but a fine incombustible dust. Coke gives off carbonic acid, aqueous vapour, and sulphurous acid, all of which are incombustible products. For heating by radiation it is an excellent fuel ; but as it does not diffuse heat by flame like coal, and is therefore not so well fitted for heating large boilers, there is among some persons a strange prejudice against the use of coke as fuel. It is supposed that some vapour escapes during its combustion which renders the air of a room noxious. This is a popular error. In a chimney of quick draught, all the products of burning coke, including sulphurous acid, are rapidly carried off; and with imperfect chimneys, the use of coal will prove just as noxious as that of coke, for all coal is converted into coke in the process of burning. An ordinary coal fire consists entirely of heated coke when the volatile matters have been burnt off. For ordinary grates a mixture of coal and coke forms the best kind of fuel.

752. Good coal, where it abounds, is for ordinary purposes by much the cheapest kind of fuel; and since, within a short time, men have learned to separate from it, and to use, its illuminating gas—hydrogen in combination with carbon—as a cheap substitute for tallow, oil, and wax, it has become doubly precious to them. A person reflecting that heat is the magic power which vivifies nature, and that coal is what best gives heat for the endless purposes of human society, cannot without admiration think of the rich stores of coal which exist treasured up in the bowels of the earth for man's use. Our country is in this respect singularly favoured. Her extensive coal-mines are in effect mines of latent labour or power, vastly more precious than the mines of gold and silver elsewhere. These coal-mines may be said to afford in abundance, although not directly, everything which human labour and ingenuity can produce, or which money can buy; and they have essentially contributed to render Britain a leader in the industry and commerce of the earth. Britain has become for the time to the civilized world around, nearly what a town is to the rural district in which it stands, and of this vast city the mines in question are the coal-cellars, stored at a moderate rate of consumption for many centuries; a supply which, as coming improvements in the arts of life will naturally bring economy of fuel, or substitution of other means to effect similar purposes, may be regarded as a most valuable provision.

753. *Alleged Exhaustion of coal.*—The increased consumption of coal in this country is in a great measure due to the increased demand for iron. Every ton of rolled iron involves the consumption of six tons of coal, and when we consider the immense mass of iron required for one iron ship, or for a ship-load of iron rails which are exported in vast quantities from England to all parts of the world, we shall have no difficulty in understanding that we are rapidly reducing our stock of a most valuable and necessary article. According to Mr. R. Hunt we are not likely to exhaust our supply for several hundred years to come. There are, he states, great coal areas still untouched, one extending from Morpeth to the Tees, and three miles out into the German ocean. There are others also of large extent in Nottinghamshire, South Staffordshire, Shropshire, and Wales.*

Coal is found of different qualities. In some places it is almost unmixed carbon, and exceedingly solid, like dense coke, resulting from great pressure and great subterranean heat, which appears to have deprived it of its volatile matter. Such is the stone-coal of Wales, some of which in 100 parts contains 97 of pure carbon, with only three of hydrogen and earthy matter. In some other places the coal contains a much larger proportion of hydrogen; and the hydrogen and carbon are so combined as to be in the soft condition of pitch, tar, or rock oil. This pitchy matter is called bitumen. It is highly inflammable.

Coal in combustion is now the great agent which in the recently-invented steam-engine is performing nearly all the heavy work of the advanced civilization of the present day. It is doing the work of our railways and steamships, of the great manufactories which spin and weave our clothing, of the mines from which the coal itself is extracted, and the crude ore which coal in furnaces then converts into precious iron; and it gives us the gas for lighting, which now almost changes night into day. But, unlike corn and fruit, and the herds of tame animals, on which men subsist, all of which are as regularly renewed year after year as they are consumed, the coal of a mine when once exhausted can never be replaced. The high station of England at present among nations is due in no small degree to the extraordinary wealth of coal found beneath its surface. Yet, when the British Association for the Advancement of Science held its meeting at Newcastle in 1863, the president, Sir W. Armstrong, had to show, in his opening address, how rapidly the store of coal in this country is being reduced. The annual consumption, including exportation abroad, is now nearly twenty times greater than it was at the beginning of the century. He stated his belief, which is also that of the writer,—that with better management in the domestic use of coal, greater results might be obtained with a largely diminished consumption. To waste this precious fuel is not to act like prudent parents thinking of the interest of descendants.*

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* The coal raised from the mines of the United Kingdom in 1873 amounted to 128,680,131 tons, the largest quantity ever produced in one year. About five millions of tons are annually required for the supply of the metropolis, one half of which is used for domestic purposes.

There is no coal in the world equal in quality to that supplied by Great Britain, and it is in universal demand for the purposes of heating and lighting. The enormous amount annually extracted from the mines of this country, shows in a striking form the vast area of the ancient world which must have been covered with vegetation!

754. The comparative values, as fuel, of different kinds of carbonaceous matter, have been found to be as in the following table :—

One Pound of	Melts of Ice
Good coal	90 lbs.
Coke	84 „
Charcoal of wood	95 „
Wood	32 „
Peat	19 „

Common coal consists, as explained above, chiefly of carbon and bitumen or pitch, of which pitch again, the chief element, is carbon combined with hydrogen, one of the substances which, when separate, exist as air or gas. This pitch evaporates at and below a heat of about 600° of Fahrenheit, while the heat of combustion exceeds 1000°. When fresh coal, therefore, is thrown upon the top of a common fire, part of it is soon heated to 600°, and the bitumen of that part begins to rise as visible opaque yellow smoke. It is this which in great towns darkens the atmosphere, blackens the exterior of all the buildings, and produces many other evils. By managing a coal fire, therefore, so that it shall burn or destroy its smoke, as may be done in various ways, not only is a great nuisance prevented, but a great saving of fuel may be effected. The loss arises because the heat, which the perfect combustion of the hydrogen and carbon of the smoke would produce, is not obtained, and because these substances, in assuming the gaseous form, carry off much heat in a latent state. Details on this subject are given in a treatise published by the author in 1855, 'On the Smokeless Fire, Warming, and Ventilating,' to which the reader is referred. There is no good reason why the atmosphere of London should not be rendered as clear as that of the great city of New York in America, where only stone coal is burned, or of St. Petersburg, Berlin, and the other European cities, where winter heating is obtained altogether through close stoves.

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* The Coal Committee appointed in 1871 to examine into the exhaustion of our coal-beds, assumed that the depth for working coal would be limited by the temperature of the blood, 98°. On this theory the maximum depth of a coal-mine for working, would be 3420 feet; but there is no reason for limiting the depth at which coal can be worked by the temperature of the blood. It is believed that by adopting this criterion, the Committee have greatly underrated the stock of coal in Great Britain.

Various furnaces have been contrived for the avoidance of smoke and the perfect combustion of fuel, and several Acts of Parliament have been passed to compel the use of furnaces which shall consume their own smoke, but in spite of these enactments, the nuisance to the metropolis is maintained by the wasteful use of coal in private houses.

"*Man, by the command which he has acquired over heat and fire, can produce artificially the climate which suits his constitution in any part of the globe.*"

755. It is a remarkable fact in nature that living animal bodies have the property of maintaining in themselves a certain nearly uniform temperature, whether surrounded by bodies that are hotter or colder than themselves. Persons passing the winter near the north pole, where they are breathing air cold enough to freeze mercury, still have in them their natural warmth of 98° Fahrenheit; and the inhabitants of India, where the thermometer sometimes stands at 115° in the shade, have their blood only 98° warm.

756. In the valley of the Indus and in Upper Egypt, the thermometer has been seen standing at 138° to 140°. The effect of breathing such extremely heated air is to produce copious perspiration. The evaporation of this from the skin is a cooling process, and tends to keep down a high temperature within the body. The Turkish bath furnishes another proof of this wonderful power in the living body to resist a high external heat. In some cases the temperature to which a human being has been exposed in this hot-air bath has been as high as 170°. As a rule this temperature is only gradually reached. The effect of breathing air so heated, is to produce a feeling of suffocation, dizziness, and a most rapid circulation. As this is the degree of heat at which the albuminous principle of the blood coagulates, nothing but a rapid circulation combined with vital force, can prevent the liquid blood from becoming consolidated in the vessels.

757. In the mammalia generally the temperature of the body averages 101°; in birds it is as high as 107°, and sometimes reaches 111°. This very high temperature is observed chiefly in the smaller species. These temperatures are maintained, as in the human body, in spite of constant changes in the surrounding atmosphere, and their maintenance is, as we shall see presently, absolutely necessary to life, and to the due performance of those functions of the body on which life depends. Perhaps we can point to no greater contrast between living and dead matter, than is shown by the resistance of a living body to the equalization of temperature.

On what does this power of resistance depend? Assuredly not on the physical and chemical properties of the solids and fluids of the body, for so soon as death takes place the body of an animal begins to cool, and the cooling goes on as with inert or inorganic matter, until the temperature is the same as that of surrounding objects.

We speak of warm-blooded and cold-blooded animals, reptiles being placed generally in the latter class. John Hunter proved that this does not imply an absolutely higher or lower temperature, but simply a temperature which is liable to change with the atmosphere. Reptiles have generally a temperature a few degrees higher than the medium in which they live, and they may feel hot or cold according to the changes in the external atmosphere.

In order to maintain a uniform temperature in the living body, heat must be produced in sufficient quantity to compensate for that which is lost by radiation, by convection in a moving atmosphere, and by evaporation of fluids from the exposed surfaces.*

758. Every kind of animal has a temperature proper to it, and in the diversity of animals, are found creatures fitted to live in all parts of the earth; what is wanting in internal bodily constitution being found in the admirably adapted covering which protects them—a covering which is a product of their food, and grows from their bodies in the form of fur or feather, in the exact degree required, and even so as in the same animal to vary with climate and season. No such covering is possessed by man; but his reason, by which he subjects all nature to his use, enables him to clothe himself as befits the part of the globe in which he chooses to dwell.

759. On this subject Dr. Kirkes remarks that the loss of heat sustained by animals, differs greatly according to circumstances, and there is a similar difference in the degrees of power which they possess of adapting themselves to such differences. Some live best in cold regions, where they produce abundant heat for radiation, and cannot endure the heat of warm climates, where the heat which they habitually produce would probably be excessive, and by its continual though perhaps small excess, would generate disease: others, naturally inhabiting warm climates, die if removed to cold ones, as if because their power of producing heat, were not sufficient to compensate for the larger abstractions of it by radiation. Man, with the aid of intellect for the provision of artificial clothing, and with command over food, is in these respects superior to all other creatures, possessing the greatest power of adaptation to external temperature, and being capable of enduring extreme degrees of heat as well as of cold without injury to health. His power of adaptation is sufficient for the maintenance of a uniform temperature over a range of 226° of Fahrenheit's thermometer,* a power which is shared by a few domestic animals.

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* Dogs, it is well known, when much heated by exercise, or by the weather, do not perspire through their skins, but throw out by their long humid tongues, a large evaporating surface by which their high temperature is reduced.

760. The power in men and animals of preserving their peculiar temperature has its limits. Intense cold coming suddenly upon a man who has not sufficient protection, first causes a sensation of pain, and then brings on an almost irresistible sleepiness, which, if indulged, proves fatal. Sir Joseph Banks, in one of his voyages, having gone on shore near the cold Cape Horn, and being fatigued, was so overcome by the feeling mentioned, that he entreated his companions to let him sleep, if but for a few minutes. His request, if granted, might have allowed to come upon him the sleep of death, as befell so many of the hostile army retreating from Russia through the snows of 1812, when in one night the thermometer fell to 19° below zero, and, according to the bulletin, 30,000 horses perished, besides men. Cold in less severe degrees, acting through longer periods on persons imperfectly protected, induces a variety of diseases, which destroy life more slowly,—as many of the winter diseases of England.

761. The human race, when not possessing certain arts of civilization, naturally seek a warm climate, such as exists over vast regions on both sides of the equator. There the sun's influence is strong and uniform, producing a rich and warm garden, in which human beings, however ignorant of the world around them, would have all their necessities at once supplied. The ripe fruit is there always hanging from the branches; of clothing there is required only what moral feelings may dictate, or what may be supposed to add grace to the form; and as shelter from the weather, a few broad leaves spread on connected reeds, complete the tropical hut. The human family, in multiplying and spreading in all directions from such a centre, would find, to the east and west, only the lengthened paradise, with slightly varying features of beauty; but to the north and south the changes of season, which cause the bee of high latitudes to lay up its winter store of honey, and send migrating birds from country to country to find the required warmth and food, would also rouse man's energies to protect himself. His faculties of foresight and contrivance would come into play, and through these and his power to produce at will and to control the wonder-working principle of heat, he is enabled to exist in all climates, from the equator almost to the poles.

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* See table, p. 506, in which the extreme of cold observed by Erman in Siberia was −72°, and the maximum of heat in West Indian steamships 154°.

Influence of disease on Animal Heat.

762. Although the average temperature of the body in a state of health is from 98° to 100°, it is liable to be increased or diminished by disease, and the clinical thermometer is now much used by physicians as an indication of recovery or approaching death. The temperature of the body is usually determined by placing the thermometer under the tongue or in the armpit. Clinical thermometers, which are specially constructed for these observations, are of extreme delicacy, and their accuracy is generally determined by comparison with a standard kept at the Kew Observatory.* The delicate thread of mercury by which the measurements are made is less than the $\frac{1}{100}$th of an inch in diameter. In one of these instruments, which the writer examined, there were five divisions to a degree, and three degrees corresponded to half an inch of the tube. The temperature, therefore, admits of measurement to small fractions of a degree.

The cylindrical portion of the tube containing the mercury (fig. 180), is about half an inch in length, is thin, and presents a large surface, so that it may be quickly affected. The graduation begins at 90°, and does not extend beyond 110°, this being the ordinary scale for the extremes of temperature usually observed. In children the temperature is often as high as 102°. Of the external parts, the temperature is observed to become lower, the further they are from the centre of the body. Thus on the thigh the temperature will be 94°, and on the sole of the foot 90° (Davy).

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* This is the rule regarding the thermometers made by Pillischer of Bond Street. Each instrument is accompanied by a special certificate setting forth any differences.

Fig. 180.

In scarlet fever and typhus the temperature is observed to rise to 107°, and in children affected with these diseases, the skin has been observed to have a temperature of 108·5°. In a girl of sixteen, suffering from inflammation of the lungs, the temperature gradually rose up to the fifth day, when it stood at 107·5°. On the sixth day it fell to 104°. This is considered to be the average temperature of fever-heat. In a youth of twenty, also attacked with the same disease, it was noticed that in thirty-four-hours his temperature had risen to 110°. On the next morning it had fallen to 99°. It has been stated that 110° is the extreme limit to which the temperature of the human body could be raised without a fatal termination, and it is highly probable that this statement is correct, assuming that it is maintained for a certain time. In a fatal form of rheumatic fever it has been observed that if the temperature quickly reaches 108° or 109°, the patient dies.

763. Delaroche found that animals died when kept in air heated gradually to 13° above their natural standard. Rabbits and birds have also died when, from exposure to great external heat, their temperature has risen 9° above the natural standard.

In a fatal case of injury to the spine the temperature rapidly rose before death to 111·2°. In another instance in which death took place seventeen hours after the injury, the temperature rose to 110°.

Dr. Wilks states that a temperature of 109° or 110° is incompatible with life, and thus we have at last found a clue to the cause of death in sunstroke and in some remarkable disorders. The former, which is more correctly called heatstroke, may occur in a hot climate in the night as well as the day, and is due to the sudden rising of the temperature of the body from the external heat, and inability to throw off the retained heat from some peculiar state of the atmosphere. As a summary it may be said, if the temperature of the body rises 10° or 12° above the normal state, the blood and muscles undergo a change, and life must cease.

The administration of various drugs has been found to influence the temperature of the body. Dr. Burness found that medicinal doses of morphia and strychnia raised it from 99° to 101·2°; opium and atropia raised it to 105·6°.

The lowest temperature which can support life is unknown; but when the heat of the body is much lowered, all vital action is suspended, and death takes place.

In some diseases, as in Asiatic cholera, the temperature of the body has been as low as 77° or 79°.

Source of Animal Heat.

764. It was for a long time a received opinion among physiologists that the chief source of animal heat, was a slow kind of combustion taking place in the lungs between the oxygen of the air which enters the chest in breathing, and the carbon derived from the food, and contained in the blood circulating through the lungs. Carbonic acid and water—watery vapours—were produced and expelled in breathing, while the heat arising from this slow union of oxygen with carbon and hydrogen, was carried off by the blood and distributed throughout the body.

The changes in the blood produced by breathing, are elsewhere described (see *Animal Physics*). It may now be stated that, besides a striking change in colour, the oxygenated blood being of a bright florid red, there is a slight difference in temperature. It contains more oxygen, less carbonic acid, and less nitrogen. According to Magnus, the quantity of oxygen contained in arterial blood, is twice as great as that in venous blood, being about ten per cent. of the volume of the former, and only five per cent. of the volume of the latter. The quantity of carbonic acid is equal to twenty per cent. by volume in the arterial, and twenty-five per cent. in the venous.

These facts prove that the lungs do not act as a furnace to supply heat to the body. They are no warmer than other parts. It has been found, indeed, that the temperature of the blood in the left side of the heart, after it has traversed the whole of the lungs, is not more than one or two degrees higher than on the right side before it has been distributed through these organs.

The oxygen received into the lungs penetrates the blood through the walls of the air-cells, and displaces the carbonic acid already contained in them. The oxygen is partly dissolved by the blood, and partly combined with the red colouring particles (oxygen carriers). It is thus transferred to the capillary system of vessels, and brought in contact with the waste elements of the tissues, which are fit for oxidation and removal from the body. It is estimated that one half of the oxygen thus disappears from the arterial blood, while an equivalent quantity of carbonic acid and water is formed. The arterial is thus changed into venous blood all over the body, and the heat given out in this constant production of carbonic acid and water is distributed over a very wide area. The venous blood, containing carbonic acid, thus collected from the waste structures throughout all parts of the body, is carried to the lungs, where a portion of it is thrown off, and its place supplied by a great portion of oxygen.

765. From certain chemical properties possessed by the red colouring particles of blood, there is reason to believe that a part of the oxygen received into the lungs, passes into the blood in the state of *ozone*—a condition in which it is best adapted for ready combination with hydrogen and carbon. The oxidation-changes, therefore, by which heat is maintained in a living animal, instead of being confined to the lungs, are actually taking place over the whole of the body. The circulating oxygen combines with the carbon and hydrogen of the wasted tissues, and in this process of oxidation, as much heat is given out, as under ordinary combustion, although it is much more slowly evolved, the amount of heat depending on the quantity of material oxidized.

Attempts have been made to determine the quantity of carbon and hydrogen daily expelled from the lungs, based on the increase of carbonic acid and aqueous vapour contained in the expired air. As to the carbon, assuming that the expired air contains only three per cent. of carbonic acid (the lowest), and that 540 cubic inches of air are expired in one minute, it would follow that this would contain 16 cubic inches of carbonic acid, weighing 7·52 grains = 2 grains of solid carbon. This would be equivalent to 6 ounces of carbon or solid charcoal eliminated from the body by the lungs daily; but it is probable that the actual quantity is greater than this. Expired air, according to circumstances, may contain from three to ten per cent. Assuming an average of six per cent. the quantity of carbon oxidized and thrown out from the lungs in twenty-four hours, would be equivalent to 12 ounces of charcoal!

The quantity of water representing the hydrogen of the waste tissues, as well as the vapour of the blood expelled from the lungs in twenty-four hours, has been estimated at from 6 to 27 ounces. In combining with hydrogen, oxygen evolves nearly three times as much heat as in combining with carbon. From the slow oxidation of these two elements, animal heat is chiefly derived.

This heat-producing power is eminently under the control of the nervous system.

766. It has been stated that when a person dies, the body gradually cools until it has fallen in all parts, to the temperature of the room in which it is placed. There is, probably, no more certain sign of real death than this, although some remarkable exceptions have been noticed. In some fatal cases of Asiatic cholera, although the bodies had in the first instance cooled, the temperature subsequently rose to 87° and 92°. In some fatal diseases of the brain the temperature of the body has risen after death from 104° to 111°. In a fatal case of small-pox, Mr. Simon states that after death the temperature rose to 104° and 113°. Other observers have met with similar instances of a much higher temperature appearing after death, than was observed in the body just before death. It is difficult to explain these facts. No physical cause could be assigned for them. As breathing had for some time entirely ceased, they could not be assigned to any circulation through the lungs. But by the stoppage of the heart's action, circulation had ceased throughout the body. Certain chemical changes were probably still going on in the capillary system sufficient to account for the production of heat.

Artificial Climate producible by the arts of warming and ventilating.

767. The four essentials to the life and health of human beings are *pure air*, *warmth*, *aliment*, and *rest*, *alternating with action.* An individual if deprived of the first, dies in a few minutes, as by drowning or any other form of suffocation; if deprived of the second, he dies in a few hours, as when overwhelmed in a snow-storm; if deprived of the third, he dies in a few days, as when left on a bare rock after shipwreck; and if deprived of the fourth, he dies in a few days, weeks, or months, according to other circumstances. Want or faulty management in regard to the first two of these, are the chief causes of much of the imperfect health and the premature mortality suffered by the inhabitants of changeable climates.

Human beings living in the savage state without houses, use fire principally for the purpose of cooking food, the fuel being wood burning on the ground in the open air. A very small portion of the heat so produced, is turned to account, the gross amount being dissipated into space, partly by radiation and partly by being carried away in combination with the smoke.

Of fire burning in an enclosed space, all the heat is retained, giving warmth to the substance of the walls and to the air within them. It would have been, therefore, a very simple affair in cold weather to warm a closed apartment to any desired degree by lighting a fire in it, but for the fact that the smoke and other products of combustion are destructive to life.*

When the object was, therefore, to warm the air in any dwelling by a fire, it was found necessary to have an opening in the roof or ceiling by which the smoke might escape ; or the fire had to be made in an enclosed space beneath the floor, through which the heat would slowly penetrate by conduction ; or it might burn in a close receptacle in the room, to be called a stove, constructed of brick or other material, and having a channel for smoke leading directly to the outer atmosphere. In England, up to a late time, it was common in spacious halls, as of colleges, courts of law, and elsewhere, to have a great brazier or hearth near the middle or at one end of the room, with an opening for smoke above.

768. It was an important advance in the art of warming rooms by open fires, when the fuel was placed against the wall to radiate around, and a chimney-flue was constructed in the wall over it to carry away the smoke without allowing any mixture with the air of the room. The arrangement of the fireplace and chimney in the wall had become general in this kingdom in the last century.

In countries where the winters are colder than in England, as in the northern continental parts of Europe, it is found that sitting-rooms cannot be satisfactorily warmed by open fires of any magnitude, because of the loss of heat through the wide chimney, and as a consequence, close stoves of masonry or of metal are universally used, as well in royal palaces as in the dwellings of the poor, not from the motive of saving fuel, but for the sake of comfort and health.

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* Although it is now generally known that for the healthy performance of respiration, we require a regulated supply of pure air and the simultaneous removal of that which has been vitiated by combustion, there are many educated persons who warm their dwellings by stoves in which gas or charcoal is burnt, without any provision for carrying off the products. Under our patent laws, stoves on this principle have been allowed to be patented for general use, and the public have been led to believe that what is called patent fuel (charcoal) can be burnt, and give out heat without removing oxygen and substituting the injurious carbonic acid. A proper Sanitary Board would not allow such dangerous methods of warming to be made the subject of a patent. One of two results must follow. Either the stove gives out no. heat, and is therefore useless, or in proportion to its evolving heat, it vitiates the air, and renders it unfit for breathing.

769. At the beginning of this century, Benjamin Thompson, more commonly known as Count Rumford, while engaged with other philanthropists in establishing the Royal Institution of London, in which, since then, Davy, Faraday, and other distinguished men have laboured so usefully for the public good, proved that in the common open English fireplace more than seven-eighths of the heat produced, was carried away with the smoke to waste; and he ascertained and taught that the single change of narrowing considerably the throat of the chimney would save nearly half the fuel.* Innumerable projects for further improvement have since then been offered, for which patents have been taken, mostly, however, by persons who had little scientific knowledge on the subject, but none of them have been accepted, like Rumford's, as generally useful. The writer has noticed this subject in a short treatise adapted for popular instruction, and has suggested certain remedies.

770. THE OPEN FIRE-GRATE.—The grate is a cage or receptacle for fuel, about ten inches deep, fourteen inches broad, and nine or ten inches from back to front. It has usually two or three bars of iron in front, the sides and back are of iron or fire-brick, and the bottom is an iron grating allowing air to enter and ashes to fall out. There is left a large open space between the fire and the smoke-flue above, causing much of the waste. To prepare for lighting, the grate is charged with common bituminous coal, having firewood and paper beneath. When the paper is lighted, combustion gradually spreads, causing much smoke and tarry vapour to arise, part of which is deposited in the flue as soot. Slight causes may send part of the smoke back into the room. The fuel being consumed rapidly, requires frequent renewal, and hence constant attention and poking are necessary to obtain any approach to uniformity of action. Strong currents of cold air flow from the doors and windows towards the chimney, and without this the heated smoke and vapour would not ascend.

A great aim in regard to such open fires has been to lessen the formation of smoke. The writer saw that much good might be obtained by causing the fire to burn like a candle from above downwards, and by using the poker as a simple lever to lift the fuel as required on a movable bottom. This arrangement is now employed to a considerable extent.

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* According to Faraday an ordinary fire consumes in twelve hours forty pounds of coal, and this, by combustion, spoils 42,000 gallons of air, and causes at the same time to pass up the chimney 200,000 gallons of air.

English grates, by slight changes in their construction, can be made to effect several of the ends sought, thus—

1st. The surfaces of the back and sides of the grate should be continued vertically, in fire-brick or clay, to the chimney-throat, so as to contract the open space between the burning fuel and the throat.* This prevents the great waste of heat caused in common grates, by the mixing of much of the pure warmed air of the room with the smoke, which must ascend the chimney to escape. 2nd. A throttle-valve, or a sliding damper, may be placed in the chimney-throat, with its handle projecting in front, so that the size of the passage may be regulated at will, and its state may always be known. This damper can be so far closed as to leave a passage for little more than the true smoke, or hot foul air rising directly from the fire. Thus will the flue be filled with hot air, almost undiluted, and the great heat will cause a chimney-draught much stronger than exists with the common grate, absolutely preventing any return of smoke into the room. Such a draught will also quicken remarkably the ventilation of the room, through the opening made near the ceiling to receive the balanced ventilating-valve, and it may be made to draw through that opening the hot impure air arising from the burning of candles or lamps, or from other sources. 3rd. On the bottom of the grate can be laid a plate of sheet iron, covering it to within about half an inch of the border all round, so that only a little air may enter there, and a length of plate-iron may be placed to rest on edge, as a lining or shutter between the lower bar and the bottom of the grate—still further preventing the entrance of air there. 4th. To prepare for lighting the fire at the top and making it burn downwards, the grate may be filled with common coal to near the level of the upper bar, and upon that, pieces of twisted paper and firewood will be laid as usual, and over the wood a layer of the cinder or caked coal left from the fire of the preceding day. The combustibles being so arranged, and a match being applied to the paper, the fire, by reason of the strong draught, blazes up with singular rapidity. It will burn for many hours, and if the grate be deep, even for a whole day, without being touched. In the evening, when the fuel is nearly consumed, the fire may be extinguished instantly by lifting off one or two of the remaining pieces. At any time when desired, the fire, by a touch of the poker, and sometimes by the application in front of a sheet blower, may be excited to great activity. Fresh air may be admitted to the room through a channel from the outside, which discharges the current under the fender, and that air, tempered by contact with the warmed fender, is then diffused all around.

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* No greater space should be left between the fire and the opening of the flue than is necessary to allow of the passage of the machine used for sweeping.

A grate, constructed to act without re-charging for a long day, as above described, has beneath the firebox a receptacle for coal, which coal, supported on a movable piston-like bottom, can be easily raised, when there is need, by a hand using the poker as a simple lever. At any time a lump of coal placed on the very hot upper surface of this fire, blazes quickly and lasts long, giving out hardly any smoke. Since the publication of the writer's book, various manufacturers have engaged in making stoves with the simple lever to lift the coal, but wishing to claim some peculiar new merit, have often deviated so as to fail in their object.

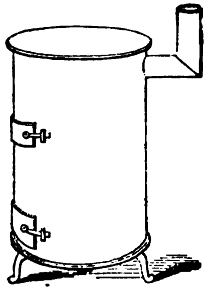

Fig. 181.

771. THE CLOSE STOVE.—The old form of this stove, with its narrow flue to carry away the smoke, is here sketched (fig. 181). By such a stove, a close room can be readily warmed to any desired temperature at the cost of a fourth part of the fuel required in an open grate. But this stove has important defects. It scarcely at all promotes the ventilation of the room; hence the air soon becomes irrespirable. It may vitiate the air of the room by becoming overheated; and there is much difficulty in regulating satisfactorily the rate of combustion. Notwithstanding these objections, close stoves are the chief means of warming dwelling-houses during the winter, in the northern parts of continental Europe. The writer, when his attention was drawn to the subject, in relation to the preservation of health, saw the possibility of connecting with this kind of stove, such a self-acting current-regulating air-valve as would completely remedy the evils above referred to.

The fire, when once lighted in this stove, if properly attended to, will burn uninterruptedly night and day for the whole of the winter. It will maintain in the room a temperature of about 62° of Fahrenheit, or higher if desired, and if the room-door is left open, the warmed air issues to the staircase, and so pervades the whole house. An air-channel under the floor, direct from the outer atmosphere, having an area of eight inches by four, admits fresh air immediately under the stove to be warmed, and to spread. Experience in many other cases has shown that such a self-regulating fire in the entrance-hall of a house, goes far to secure to the inhabitants, the advantages of the climate of the south of Europe or Madeira. It may also save to many invalids, the pain of banishment from home and its comforts.

The current-regulating air-valve for close stoves, on which their important qualities depend, is here represented by a sectional diagram (fig. 182).

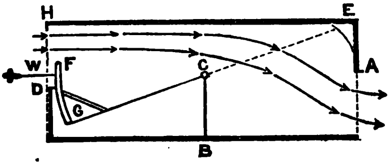

Fig. 182.

The strong lines mark the external square tube or case, about four inches long, and half as wide, to be fitted on by the end, A, to an entrance of the ash-pit. The arrows show the direction of the air-current passing through. The line, E, marks the movable internal part which modifies the current. It is a lever-frame perfectly balanced and turning on the upper edge of the cross partition, C B, as its axis. One half or arm, C E, of the lever, is a breadth of wire-gauze through which the current of air forces itself, causing a downward pressure and motion. The other arm, C G F, carries at its end a bent plate, G F (here seen edgeways), which, on being raised as the lever moves, becomes a shutter narrowing the air-entrance, H D.

The self-weakening action of the current would soon extinguish a fire dependent on it, if there were not a small weight, W, placed near the extremity of the arm at F, which counteracts, and by pressing down the shutter, F G, admits just air enough for its purpose, and the current then continues quite uniform until changed by lessening or increasing the weight, W, or altering its power by moving it nearer to or further from the centre of motion, C. It will be observed that the current blowing perpendicularly on the bent plate, F G, has no effect either to raise or lower it. This kind of valve may be put on any close stove with much advantage, and it will be found a useful addition to all channels serving for ventilation.

772. The subjoined woodcut (fig. 183) exhibits in section the complete self-regulating, self-feeding close stove above referred to.

The letters, A B C D, mark the external case, which prevents the intense heat of the inner stove, *a b c d*, from damaging the air of the room. It is not allowed to be hotter than a tea-urn containing boiling water.

F is the regulating valve, *c* and *d*, the fire-brick lining of the fuel-box.

H, the coal-reservoir or hopper containing coal enough to last for twenty-four hours, which falls down as the coal below is consumed. It is charged with coal through the lids, *k* and K, both of which are rendered air-tight by having their turned-down rims or edges dipping into grooves filled with sand, at *e e*.

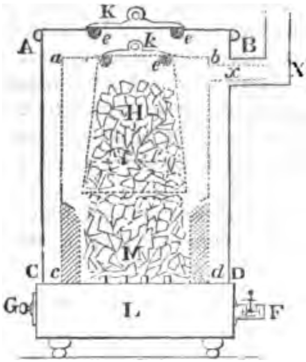

Fig. 183.

The burned air from the fire, M, rises up in the space between the hopper and the inner stove case, to pass away by the internal flue, *x*, into the other flue, X, of the outer case.

L is the ash-pit, G the ash-pit door,—ground close.

M is the fuel intensely ignited below, where the fresh air is entering to maintain combustion.

The fuel must be good stone-coal (anthracite) or coke, or a mixture in the proportion of one part of coke to two of anthracite. Common bituminous coal must not be used, since this produces gases which may cause an explosion by admixture with air.

The Mechanical Equivalent of Heat.

773. Within a recent period, certain means have been devised for the purpose of measuring accurately the expansive force of heat as a mechanical agent, and for determining many important relations existing between heat and the other forms of force operating throughout nature.

We may recall that to measure anything is to adopt some convenient amount or quantity of that as a unit of reference, and then to find how often that unit is contained in any new quantity. Thus, if a convenient handful of some substance be called a pound-weight, any other quantity of ponderable matter is accurately measured when the number of such pounds contained in it is ascertained. So if the average length of a human foot be called a foot-measure, any greater length is determined by finding the number of such feet contained in it. It follows that a foot square is a convenient unit for surfaces, and a foot cube for bulks. A measure for temperature is the length of the mercurial column of a thermometer, standing between the fixed points of freezing and boiling water, when divided into a certain number of equal parts, to be called unit degrees of temperature. Then for quantity of heat, as distinguished from temperature, a convenient unit is that quantity which just suffices to raise the temperature of one pound of water one degree of the standard thermometer. Lastly, in relation to the present subject, a convenient *unit of force* is that which can lift one-pound weight through one foot of height,—an amount now called a *foot-pound.* By referring to such standard units once chosen and generally agreed upon, all questions respecting the mechanical equivalents of heat and other forms of force can be satisfactorily answered. An example follows.

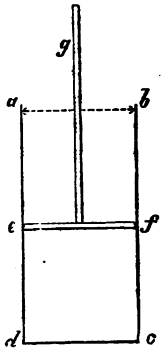

Fig. 184.

Let the outline, *a b c d*, indicate a vessel like the barrel of a pump or steam-engine, of a foot square in transverse area, having in it a movable close-fitting piston, *g e f.* That piston, when one foot from the bottom, would shut up below it in the space, *e f c d*, just one cubic foot of air. The surface of the piston being an area of a square foot, or 144 square inches, will be bearing on its upper surface the atmospheric pressure of 15 pounds on every inch, in all 2160 pounds, or nearly twenty hundred-weight, which in a state of rest will be exactly balanced by the resisting elasticity of the confined air below the piston. Now experiment shows that by giving heat to produce 490 additional degrees of temperature in the air beneath the piston, the bulk or volume of that air will be just doubled, and it will gradually push up the piston to the line, *a b*, two feet from the bottom. Thus rising, the piston lifts a weight of 2160 pounds through one foot of height. If instead of the atmosphere pressing down the piston, there were a mass of

2160 pounds of lead resting on it and no air, the result would be the same.

Then, knowing further the weight of a cubic foot of air, and the the so-called capacity for heat of air at different densities, as compared with an equal weight of water, there will be no difficulty in determining the quantity of heat absorbed or expended in lifting this vast weight. The ascertained fact is, that the amount of heat which warms one pound of water one degree of Fahrenheit, (the so-called thermal unit) has force to lift one pound weight of anything 772 feet, or a weight of 772 pounds one foot. This expansive force of the unit of heat, as compared with the downward force of gravitation, is called the mechanical equivalent of heat.

774. Persons, before studying this subject, would be far from thinking that so small an amount of heat could produce such a powerful mechanical effect, but now there is no room for doubt. This fact, when once understood, explains many other marvels; for instance, the force of a single steam-engine doing the water-pumping work of six hundred strong horses. Then it is the force of the sun's hot rays which is daily lifting to the clouds, in evaporation from the water-surfaces below, the enormous quantity of water which falls again all over the globe as rain and snow, ultimately to fill the countless river-channels, great and small, which return it to the sea. Then it is the heat of the sun which produces all the motions of the atmosphere called winds, including the variable breezes of temperate climates, the strong and steady trade-winds of the tropics all round the earth, and the furious hurricanes which occasionally sweep over wide regions. And, lastly, the whole surface of the ocean is constantly heaving in waves, low or lofty, produced by the force of the wind blowing upon it.

In the last paragraphs are set forth phenomena in which heat acts mechanically to produce motion in heavy masses, with a force exactly proportioned to its quantity. We may now state, in addition, that motions of masses so produced can, when suddenly arrested by obstacles, reproduce the exact amount of heat which caused them, either of the two forms of force being thus convertible into the other.

775. It had long been familiarly known that certain motions or masses, while exhibiting the phenomena of friction, percussion, condensation, and others, generated heat, but the relations were not accurately determined. Thus a soft iron nail laid upon an anvil, and receiving in rapid succession powerful blows of a hammer, becomes hot enough to light a match. In the case of the mutual percussion of flint and steel in the old gun-lock, small portions of one or both are struck off in a state of white heat, and the minute particles of the iron become incandescent and burn in passing through the air. The heat produced by rubbing strongly against each other two pieces of dry wood, has been elsewhere described as the means commonly used among savages to light their fires. Men warm their cold hands in winter by rubbing them against each other, or against their coat-sleeves. The axles of a heavily-laden waggon, or of the rapidly revolving wheels of a railway-carriage, if left without grease or oil, may be so heated by friction as to inflame the wood and set the carriage on fire. The line attached to a whale-harpoon, as it runs over the side of the boat, when the whale dives after being struck, requires to have water constantly thrown upon it to prevent it setting fire to the boat. The cable of a ship drawn very rapidly through the hawse-opening, produces there intense heat and smoke. When a great ship is launched from the builder's yard, and glides along the sloping beams to the water, a dense smoke usually rises from the points of rubbing contact.

Other examples present themselves in daily life. The friction of the wheel of a heavily laden waggon on a paved road, when the wheel is locked and prevented from revolving, generates intense heat, indicated by the production of smoke and vapour. A man cannot venture to touch the iron skid of a wheel which has been used in the long descent of a hill. Another remarkable instance of the conversion of the force of percussion into heat, is seen in firing a leaden bullet against an iron screen. The heat generated is such as often to carry it to the point of fusion, which is not less than 600°.

776. In all these cases, however, the amount of heat produced is variable, and it had not been accurately measured until the experiments of Joule, Mayer, and others, proved that the quantity of heat evolved is definite and exactly proportioned to the mechanical force expended. Thus, a body falling from a height, and arrested by collision with another body on the ground, produces just as much heat shared between the two as, if again used to dilate air or steam, would lift the body to the height from which it fell ; nearly as the momentum of a pendulum acquired by descending from one side of its arc to the centre, just suffices to lift it to the same height on the other side. Any liquid poured out and falling into a vessel below, becomes heated in exact proportion to the height of fall. Any liquid, as water, oil, or mercury, driven round or churned in a vessel by a paddle-wheel moved by a falling weight, is warmed just in proportion to the weight and the height of its descent. There are similar relations and correspondence between heat and other forces and actions as of electricity, chemical combination or decomposition, and muscular power; and there is reason to believe that all these are convertible into one another in fixed proportions.

By the terms mechanical equivalent of heat, we are, therefore, to understand the quantity of heat required to produce a certain amount of work or certain mechanical results. It is susceptible of measurement and expression in a formula, as it has been elsewhere explained (Art. 192).

777. In 1842, Dr. Mayer, of Heilbronn, made a calculation of the equivalent of heat based upon certain theoretical grounds. In the following year Dr. Joule, of Manchester, performed many experiments on this subject, the results of which are considered to establish, in a conclusive manner, the exact mechanical relation or equivalence of heat. He caused paddles to turn in vessels of water, of oil, and of mercury, by means of a weight falling through a given height; and, measuring the increase of heat generated by the agitation of the liquids, he found within the legitimate limits of experimental accuracy, that from the same amount of mechanical energy the same amount of absolute heat was in every case produced, account being of course taken of the fact, that the *sensible expression* by the thermometer of the heat communicated to the water, would be only one-thirtieth of that in the case of mercury.

Percussion, as it has been already observed, offers a simple and direct example of the conversion of mechanical force into heat. If a ball of iron or lead be allowed to fall from a height of say ten feet upon a block of iron or lead, the moving force expressed from gravity would be stopped and apparently destroyed by the percussion. In reality, however, it has been converted into an equivalent non-locomotive or internal motion, which for such a small height of fall might escape observation, but which, for a great height or after repeated falls, would be very appreciable.

The experiments of Joule, Mayer, and others, show that, with a double height of fall, a double degree of heat is created; also that, knowing the weight of any body and the height from which it fell, we can at once determine the amount of heat that would be generated by percussion from that height. The average of a great number of experiments made by Joule, gives the quantity of heat generated by one pound in falling from a height of 772 feet, and thus converting all its moving power into heat by percussion or friction, to be such as would raise one pound of water by one degree (Fahr.), or one pound of mercury by thirty degrees.*

778. It follows, then, that, knowing the weight of any body and the rate at which it is moving, and having deduced the height from which it would have to fall, in order to produce the same velocity, we can estimate what amount of heat would be produced, if its motion were to be suddenly converted into heat by collision or percussion. A fall of 772 feet corresponds to a velocity of about 223 feet per second (Art. 139); a fall of 4, 9, &c., times 772 feet corresponds to a velocity of 2, 3, &c., times 223 feet per second, but to an increase of 4, 9, &c., times the quantity of heat if the fall be stopped by percussion. Hence, just as by doubling the velocity of a cannon-ball we quadruple its penetrating energy, so we quadruple the heat-motion or energy derivable from friction or percussion.

On the other hand, if we know the amount of heat generated and the weight of the colliding masses, we can calculate the velocity of collision. The chemist explains the burning of a candle, or of common gas, as the union, in virtue of chemical affinity or attraction, of the carbon particles of the candle or gas with the oxygen particles of the air : the physicist goes one step farther and sees, in the atomic attraction of the chemist, an intense atomic *projectile force*, as it were, which produces the heat and flame in exactly the same way as the percussion or collision of large visible masses produces heat in them ; and if we knew the absolute weights of oxygen and carbon-particles, and the degree of heat generated by a given number of them, we could at once tell the velocity with which they collide. This subject is, however, at present beyond the reach of experiment. It is demonstrable that masses of matter produce heat by percussion or friction ; and it is inferred that where heat is evolved, as in the chemical union of substances, the ultimate atoms suddenly acquire an intensely rapid movement among themselves, so as to become incandescent, and emit heat as well as light ; in other words, that chemical union operates by producing a violent mechanical motion among atoms which they did not previously possess. In the production of heat by friction or percussion, the substances undergo no change; they are the same after as before. In its production by chemical agency, however, the substances are no longer the same; they are converted into new forms of matter, and are so completely changed in their properties as to be no longer recognizable in the compounds produced.

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* This, as it has been already explained, constitutes a unit of heat. On the Centigrade scale, the figures would of course differ, as one degree of this scale corresponds to 1·8° of Fahrenheit. It would require the fall of one pound through 1390 feet to raise the temperature of one pound of water by one degree, or one pound of mercury by thirty degrees.

SECTION II.—LIGHT.

ANALYSIS OF THE SECTION.

Light is an emanation from the SUN *and other self-luminous bodies, becoming less intense as it spreads, and by falling on other bodies, and being reflected from them to the eye, renders them visible. Its absence is called darkness. It moves with great velocity, and in straight lines where there is no obstacle,—leaving shadows where it cannot fall. It passes readily through some bodies—which are therefore called transparent,—but when it enters or leaves their surfaces obliquely, it suffers a degree of bending or* REFRACTION. *A beam of white light thus refracted does not bend equally, but is divided or resolved into beams of the different colours seen in the rainbow. These colours, on being again blended, become white light as before.*

A transparent substance, like glass, may be so formed as, by the power of refraction due to its shape, to cause all the rays which pass through it from any point on one side of it, to bend and meet again in a corresponding point beyond it called a focus, and after so meeting and crossing, to pass on as before;—the body then, because in form somewhat resembling a flat bean or lentil, being called a LENS. *When the light thus proceeding from every point of an object placed before a lens, is collected at corresponding points behind it, a distinct image of the object is there produced, visible from any situation on a white screen placed to receive it, or in the air, if viewed from behind. The most important optical instruments, and even the living eye, are merely different arrangements of parts for producing and examining such images as those now described. When the image is received upon a suitable white surface or screen in a dark room, the arrangement is called, according to minor circumstances, a* CAMERA OBSCURA *(that is, a dark chamber), a* MAGIC LANTERN, *or a* SOLAR MICROSCOPE. *And even the living* EYE *is, in fact, but a small camera obscura, enabling the mind to judge of external objects, by the size, brightness, colour, &c., of the very minute but perfect images or pictures formed at its back part, on the smooth screen of nervous matter or sensitive membrane called the retina. The art of painting aims at producing on a larger scale such a picture as is formed on the retina, which when afterwards held before the eye, and reproducing itself in miniature upon this membrane, may excite nearly the same impression as the original objects. When the image beyond a lens, formed as above described, is viewed in the air, by looking at it from behind, in the* *line of the axis of the lens, there then exists the arrangement of parts constituting a* TELESCOPE *or a* MICROSCOPE.

Rays of light falling on very smooth or polished plane surfaces, are reflected so exactly in the order in which they fall, as to appear to the eye receiving them to be coming directly from the objects originally emitting them—and such surfaces are called plane mirrors. Mirrors may be plane, convex, or concave; and certain concave forms concentrate light, to produce images by reflection, just as lenses produce them by refraction; so that there are reflecting telescopes, and microscopes, as there are refracting instruments of the same names. Light, again, falling on bodies having rough or irregular surfaces, or which have other peculiarities, is so modified as to produce all the phenomena of colour and varied brightness seen among natural bodies, and giving to them their distinctive characters and beauty.

The decomposition of light into the colours seen in the rainbow, was first experimentally studied by Newton; and since his day the subject has been developed into the extensive science of SPECTRUM ANALYSIS, *an important auxiliary to the modern chemist and astronomer. By applying a telescope to examine the prismatic band or spectrum of a flame, we form a* SPECTROSCOPE; *and by means of this instrument we can determine, however distant the light may be, whether it is the flame of a burning gas or whether it is a solid in a state of incandescence; and by its particular lines of colour, we are able in some cases to identify the substance. Thus, the astronomer knows what metallic vapours are incandescent in the solar atmosphere (or photosphere); and can even detect the presence of well-known chemical elements in the inconceivably distant fixed stars.*

According to the WAVE THEORY *of light, different colours are simply different lengths of ethereal undulations, just as different musical notes are different lengths of aërial pulsations; and this undulatory theory has received remarkable confirmation from a large class of phenomena referred to under the names,* DIFFRACTION, INTERFERENCE, *and* POLARIZATION OF LIGHT.

Sources of Light. Light from the Sun—from Combustion. Phosphorescence.

779. The phenomena of *light* and *vision* are of surpassing interest, on account of their beauty and their utility. Their beauty is seen in the verdure of fields and forests, among the beds of the flower-garden, in the plumage of birds, in the richly coloured clouds around the rising and the setting sun, and in the circles of the rainbow. Their utility is such that, if man had needed to supply his wants by groping in utter and unchangeable darkness, even with all the knowledge now existing in the world, he could scarcely have secured his existence for a single day. Eternal night would have been equivalent to universal death. Light is at once the beauteous garb of nature, and the absolutely necessary medium of communication between living creatures and the universe around them. The rising sun converts a wilderness of darkness which, to a child, not yet aware of the regularity of nature's changes, is so full of horror, into a visible and lovely paradise. No wonder, then, if in the early ages of ignorance, man bowed the knee to worship, in the glorious Sun, the God of Nature!

780. The eye receives from every illuminated object around, nay, from every point in every object, and at every moment of time, a messenger of light to tell what is there, and in what condition. Had we the power of flitting from place to place with the speed of thought, we could not be more promptly informed.

The sense of sight contributes to our knowledge of the phenomena of the world around us, more than all our other senses put together. With the aid of the microscope, it reveals to us a miniature world of life and activity, even in the tiny water-drop, and a most wonderful complexity of structure in the minutest objects of nature. With the aid of the telescope, it gives us intelligence from the utmost bounds of space, telling us of suns and systems before which our terrestrial globe dwindles into insignificance.

The Sun is the chief source of light.

781. This truth is most strikingly impressed upon us in tropical countries, where the sun rises and sets almost perpendicularly, not allowing the long dawn and twilight of temperate latitudes, and where the change from perfect darkness to the overpowering effulgence of day, and the contrary change in the evening, take place suddenly. We may contrast this tropical effulgence with the darkness and desolation of an arctic winter. In the arctic regions the inhabitants lose the sun for many months together, and are obliged to resort to artificial light.

On what particular conditions solar light depends is not well understood; but, to use the common mode of expression, rays of heat and light are emitted from this luminary together, and they reach the earth in about the same period of time. The light is probably a result of intense heat, not arising from any cause similar to combustion on the earth, but, so far as spectroscopic examination will enable us to form a judgment, from the intense incandescence of the vapours of many metals, as well as of gases constituting the luminous atmosphere or photosphere, of the sun. To the questions, what causes this incandescence, and what maintains it with such apparent uniformity for ages, science at present can furnish no answer. The polariscope, to be afterwards explained, shows that the sun is a self-luminous body.

Light emanates from the STARS, and here, also, an examination of these remote bodies by the spectroscope and polariscope proves that, like the sun, they are self-luminous, and that their brilliant light, without sensible heat, is dependent on the incandescence of metallic vapours and gases. Owing to their enormous distance, the heat-rays which they emit do not reach the earth, but the rays of light are sufficiently penetrating to admit of optical examination and definition.

782. The artificial production of light from *combustion* is a subject more within the reach of experiment. In the preceding section combustion, as a source of *heat*, has been fully examined. It will now be necessary to consider it as a source of *light*.

The quantity of light emitted from a burning substance in general depends, first, on the intensity of the heat produced; and, secondly, on the presence of some solid non-volatile matter which is capable of receiving the heat without undergoing any change in its physical condition, and of emitting it as light.

With regard to the effect of heat in producing light, some remarks have been elsewhere made (Art. 719, p. 507). The first effect is to render a solid visibly red, and this point is reached at about 1000°; the substance then emits the less refrangible rays of light, and appears *red-hot*. As the heat is increased, it passes through the stages of orange and yellow heat, and finally, by the emission of all the rays of light, it appears as a dazzling *white* heat. Hence it might be said that light is nothing more than visible heat, and heat, invisible light, their difference being only in the degree of certain qualities. It is further assumed that they are convertible into each other. Experiment shows, however, that they admit of separation to a certain extent, and that they act differently in causing chemical combinations, and in decomposing chemical compounds.

783. When combustion takes place at a low red heat, as in the platinum-wire lamp of Sir H. Davy, the metal emits light, visible only in the dark, the metallic substance receiving and radiating the heat. Hydrogen burns with intense heat, but there is scarcely any light; indeed it may be said that the flame of pure hydrogen is invisible by daylight. This disproportion between the light and heat emitted is explained by the fact that there is no solid matter which admits of being heated to incandescence. Watery vapour is the only product, and this cannot absorb and emit the heat as light. If platinum-wire, or particles of charcoal, lime, asbestos, or iron-filings, are introduced into burning hydrogen, they receive the heat of combustion, and emit it as a very bright light.

784. *The Drummond or Lime Light.*—Lime was first used as a source of light with the nearly invisible oxyhydrogen jet, by Lieutenant Drummond in 1826. He employed it in the triangulation survey, and successfully connected the opposite shores of England and Ireland at Holyhead, a distance of sixty-four miles. In Scotland he obtained successful results on the summits of Ben Lomond and Knock Layd, a distance of ninety-five miles. Dr. Miller states that the Drummond light has been seen at a distance in a right line of 112 miles. It is probably the most powerful of all artificial lights.

785. The intense white light produced by the combustion of coal-gas, or the vapours of paraffine or rock oil, is entirely owing to the carbon atoms contained in the gas or vapour being intensely heated by the burning hydrogen, and emitting this heat as light.

The same substance emits a feeble light when the products of combustion are gaseous, and a powerful light when they are solid. Thus, in burning phosphorus in chlorine, a gaseous chloride results, and a dull flame scarcely emitting any light, is seen. If, while thus burning, the phosphorus is raised from the bell-jar into the air, it combines with oxygen and produces solid white phosphoric acid, which, being strongly heated, emits an intensely white light. The difference in illuminating power is rendered still more conspicuous, by plunging the ladle with the burning phosphorus into a bell-jar of pure oxygen.

A thin slip of zinc or magnesium, introduced into a Bunsen's smokeless flame, burns with dazzling splendour, more marked in the magnesium than the zinc. In either case a white infusible oxide is produced, which receives and emits the heat of combustion as white light. From the photo-chemical researches of Bunsen and Roscoe, it was calculated that the light of the sun's disc was 524 times greater than that of burning magnesium. So intense is the light emitted by magnesium, that a wire of only the hundredth of an inch in diameter was found to produce as much light as seventy-four stearine candles! The brightness of the light, therefore, arising from combustion, depends not only on the combustible, but on the product of combustion. Fixed substances like iron and charcoal emit a great amount of light in proportion to the heat. In all combustions in which oxygen takes a share, the greater the amount of this element consumed within a given time, the greater the quantity of light emitted. The *Bude light* owes its great brightness to the current of oxygen introduced into the centre of the coal-gas flame.

788. *Other Sources of Light—The Electric Light.*—In the production of the electric light *in vacuo* there is no combustion, the heat of the electric current is converted into light, manifested by the vivid incandescence of the particles of charcoal at the two poles. The intensity of the electric light thus emitted is considered to be equal to one-fifth, or even to one-fourth, of that of the sun.

Phosphorescence.—There are other sources of light unattended with any perceptible degree of heat, as in the luminosity of fluor-spar and other mineral substances when moderately heated, and to this, the term *phosphorescence* has been somewhat loosely applied. It is a condition in which invisible heat has been converted into visible light.

Light from Animals.—As with heat, so with light; it may be produced in the animal body as a result of vital force. This source of light is seen in the bodies of the glowworm, the firefly, and other luminous insects met with in warm countries, as also in the minute rhizopods and jelly-fish (*Acalephæ*), which often give a splendid light to large surfaces of the sea.*

In describing the powers which these minute rhizopods or foraminifera possess of secreting light, Mr. Rymer Jones observes, "Few visitors at the seaside can have failed to observe that often in the summer-time, the waves are luminous and shine with phosphorescent splendour. The ripples, as they totter towards the beach, sparkle with scintillations, and the crested waves blaze with a pale but brilliant light. The fisherman, who from his boat surveys the lambent flames that play around him, seems to float in fire. The mariner can trace his path by the long wake of light that streams behind like the train of some vast sky-rocket; or, looking from the prow, he sees his vessel, as she breasts the waves, dash from her bows broad sheets of liquid splendour. As morning dawns, the fairy vision vanishes, nor can the keenest eye perceive, in the translucent element, the tiny lamps that caused the grand illumination." The cause of this phenomenon in every part of the world has been traced to the presence of myriads of living animalcula. It shows that light may be manifested in an intense form without any corresponding degree of heat, or it might be said of these bodies that the heat emitted from them has been entirely converted into light.

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* The wingless female glowworm (*Lampyris*) is highly luminous. It emits the light from the hinder part of the abdomen, and the intensity of it can be varied at pleasure. Unless the insect is physically injured, it continues to emit light when completely immersed in water, thus showing that this does not depend on any phosphoric matter. The light has the brilliancy of the diamond, and sometimes appears coloured like the sapphire, emerald, or topaz. No sensible heat accompanies this intense production of light. It is entirely under the control of the animal, for any disturbing cause will at once render the insect non-luminous.

The *Cucujo* (*Elater noctiluens*), found in South America, has upon each side of its chest, a round spot from which there issues at night, a light so brilliant that, when several are put together in a glass vessel, it is said to be easy to read by it the smallest print.

787. Light is sometimes emitted by substances of an organic nature, before they have reached a certain stage of decay. Certain kinds of fish, such as the whiting, herring, and mackerel, have been observed to emit a pale light in the dark; and this phenomenon has been even observed in the dying and recently dead human body. The appearance thus presented is of a phophorescent kind, and it probably depends on chemical changes in the solids, although, as no sensible heat is emitted, it cannot be regarded as dependent on combustion. It is arrested by putrefaction.

Light is in some cases emitted by crystalline substances. In the sudden crystallization of sulphate of soda (Art. 671, HEAT), light has been observed to issue when the experiment was performed in a dark room. Common loaf-sugar rubbed in the dark in warm dry weather emits a pale phosphorescent light. The heat produced by molecular changes in the substance or by friction, may explain these facts. Some have ascribed it to an electrical effect.

"*Light becomes less intense as it spreads.*"

788. Light, like any other emanation from a central point, in spreading through wider space, becomes thinner or less intense in proportion as it spreads. Thus, if a taper be placed in the centre of a cubical box every side of which is a foot square, the light falling on the sides of the box will have a certain intensity there: if the taper be then placed in a similar box with sides of two feet square, there will be only the same quantity of light, but it will be spread over four times as much surface—for a square having two feet in the edge, is made up of four squares of one foot—and will, therefore, on any part of that surface, be only one-fourth part as strong or intense as in the first box; and so for any other size of box or space, the intensity will diminish as the square of the distance increases. (See Art. 19, fig. 1, page 9.)

Hence, if the earth were at twice its present distance from the sun, *i.e.*, beyond the planet Mars, it would receive only one-fourth of the light and heat which it now receives, just as a man placed four yards from a fire receives only one-fourth of the heat which falls on a man at two yards. At three times its present distance from the sun, the earth would receive only one-ninth of the light now received, and conversely, if it were only one-third of its present distance, the heat and light would be increased ninefold. A reference to fig. 1, page 9, will enable the reader to follow this statement of the law of increase and diminution.

Separation of Light and Heat. Calorescence.

789. Light and Heat are generally found associated. This is observed in the sun's rays as well as in the phenomena of combustion. They admit, however, of separation. A stream of concentrated light from the carbon-points of a powerful battery received upon a prism, is resolved, like solar light, as will be more particularly described in a future article, into the seven primitive colours of which white light is constituted. When a similar beam was passed through a layer of rock-salt it was found that heat, as well as light, traversed the salt, and produced all its usual effects. Having thus the two forces at command, Professor Tyndall adopted the following ingenious plan in order to separate them. He placed in front of the concentrated beam of electric light a rock-salt cell, containing a strong solution of iodine in sulphide of carbon. This was found to have the property of entirely arresting all the rays of light, although these were concentrated by a powerful concave mirror, the focus of rays being so adjusted as to fall at a point on the darkened side of this liquid screen. When the solution was removed, the rays of heat and light were demonstrated to exist in an intense form at the visible focal point, about six inches distant from the electric light. Substances placed in the focus were illuminated and burnt. On replacing the screen not the slightest portion of light could be seen; the rays of light were quite cut off by the solution, but the dark rays of heat traversed the opaque liquid as if no screen were interposed, and produced all their usual effects. The focus of dark rays was easily found in the impenetrable darkness, by bringing into it a variety of combustible substances. Black paper was immediately inflamed: wood, zinc, and magnesium wire instantly took fire and burnt with their usual splendour. The most interesting result was witnessed on placing thin platinum foil, or platinized platinum, in the focus of dark rays. It was speedily rendered white-hot, and emitted a strong light by its incandescence. Other substances had undergone combustion, and had emitted light and heat from *chemical* changes. The platinum underwent no change; it became luminous by simply absorbing the dark rays of heat, and at a certain temperature throwing them off as light. This incandescent platinum would have readily furnished a spectrum of seven colours like that obtained from the sun or any self-luminous body. To these phenomena Tyndall has given the name of *Calorescence*, by which term is to be understood the conversion of obscure radiant heat into light.

This experiment clearly proves that, at a certain temperature, black heat may be converted into a bright light, provided there is some substance which can receive and retain the dark heat-rays for a certain period of time.

790. It has been found that glass, coloured with carbon, by stirring a stick in it while in a melted state, has the property of cutting off the rays of light entirely, and of partially quenching those of heat. On the other hand, Melloni discovered by a series of numerous experiments that light, whether derived from the sun or from ordinary combustion, might be deprived of all heat-rays by passing it successively through water and a stratum of glass coloured green with oxide of copper. He found that the rays, on issuing from these media, did not retain sufficient heat to affect the most delicate thermometer. Light is thus separated from heat, but only as coloured light, and no process has yet been devised whereby this light can be converted into heat. By a series of ingenious experiments, Melloni was enabled to prove that the light reflected from the moon is not accompanied by heat-rays. By concentrating the light of the moon through a lens of forty inches in diameter, he obtained a strong focus of light of four-tenths of an inch in diameter. When this was directed upon a very sensitive thermo-pile (see *Electricity*), there was only a feeble indication of heat.

791. There is another fact of some importance in reference to the convertibility of these two forces. Although heat-rays and light-rays come to us from the sun, they are very unequally distributed through the spectrum. As it will be fully explained hereafter, the rays of heat are more associated with the least refrangible rays, *i.e.*, with the red, and even with those beyond the red. When a rock-salt prism, which is highly diathermanous (*i.e.*, transmits heat), is used for the decomposition of light, it is found that the maximum intensity of the rays of heat is considerably beyond the red ray, in fact, they are much less refrangible than the least refrangible of the rays of light. This clearly shows a remarkable difference between the two forces. In the annexed illustration (fig. 185) the rays of light are shown by the corresponding letters, V, I, B, G, Y, O, R. The heat-rays are indicated by the dark space beyond the red, R, and the maximum of heat corresponds to the parts marked by arrows. It was at a point in the direction of the arrows that the focus was obtained, in which the experiments above mentioned were performed.

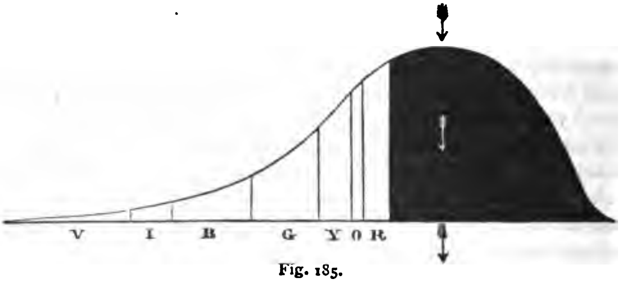

Fig. 185.

"Light falling on non-luminous bodies, makes them visible."

792. If a beam of the sun be admitted into a dark apartment so as to fall upon some object, that object becomes bright, and affects the eye almost as if it were itself luminous. It returns a part of the light which falls upon it, and it is visible in all directions, proving that it scatters the received light all around. This scattered light falling on other objects, and reflected again and again among them until absorbed—like an echo repeated many times and lost between perpendicular rocks,—may make all of them also visible, although in weaker degrees, and the whole apartment is then said to be lighted. If the direct ray be made to fall upon a surface which reflects much of the light, as a sheet of white paper or a mirror, the apartment will be more lighted :—if, on the contrary, it be received on black velvet, which returns hardly any light, the apartment will remain nearly dark. When the ray is received on a polished surface or mirror, which returns nearly the whole light, but only in one direction, and therefore throws it upon some other single object, the effect will be according to the nature of that object, and nearly as if the beam had fallen directly upon it.

Now all bodies on earth, and among these the particles of the atmosphere, diffuse among themselves the light received directly from the sun, and by so doing, maintain everywhere that mild radiance or luminosity agreeable to the sight, which renders objects visible when the sun's direct rays do not fall upon them. It is this which constitutes the shade, or non-illumined part of the body, as distinguished from the shadow where the light is directly intercepted. But for this fact, indeed, all bodies shadowed from the sun, whether by intervening clouds or by any other more opaque masses, would be perfectly black or dark; that is, totally invisible. If the earth had no atmosphere, the sun would appear as a round intensely luminous mass in a perfectly black sky. On lofty mountain summits, where half the atmosphere is below the level, the direct rays of the sun are painfully intense, and the sky is by contrast dark.

The moon is without an atmosphere, so that on the surface of this satellite, there is a sudden transition from absolute light to absolute darkness in all parts which do not receive the direct light of the sun. Under a good telescope, these deep black shadows of the mountains are easily seen, and the very sudden transition from light to darkness, is sharply marked by the irregular ridges on the illuminated side of the moon.

793. In the absence of any material substance to reflect it, light itself is, therefore, invisible. Professor Tyndall has applied this property of invisibility to the determination of the purity of atmospheric air. Smoke, or particles of dust, in any space traversed by the rays of light, reflect it and give an apparent body to the rays. When these motes, or particles, are removed from a confined quantity of air under a glass shade, by means of a small quantity of glycerine (which seems to absorb and fix them), the light traverses the shade without its presence being in any way indicated. There are, indeed, no material particles to reflect it. If, in a darkened room, a beam of light is thrown through three glass shades in succession,—the first and third containing the ordinary atmosphere of a crowded room, and the third purified by glycerine, the light is plainly seen traversing the first shade; it is entirely lost in the second, but re-appears in the third. A more delicate test of the freedom of the atmosphere from imponderable particles of suspended matter, could not be desired.

794. The green and blue colours of sea-water are ascribed by Tyndall to the presence of finely suspended matters. When solar light meets the surface of the sea, the red rays are first extinguished, orange and yellow follow as the beam penetrates deeper into the sea, green follows yellow, and the various shades of blue, where the water is deep enough, follow green. Absolute extinction of the solar beam would be the consequence, if the water were deep and uniform and contained no suspended matter. Such water would be as black as ink. A reflected glimmer of ordinary light would reach us from its surface, as it would from the surface of actual writing ink, but no light, hence no colour, would reach us from the body of the water. In very clear and very deep sea-water this condition is approximately fulfilled, and hence the extraordinary darkness of such water. The coloured rays reflected by minute suspended particles in a shallow sea, are either green or of a light blue. It also results from experiments performed by this physicist, that the blue light of the sky is entirely due to reflected light, and were there nothing in our atmosphere capable of reflecting the solar rays, we should see no blue firmament, but should look into the darkness of infinite space. The reflection of the blue is effected by minute colourless particles seen in the mass. Smallness of size alone is requisite to insure the selection and reflection of this colour. While the blue is owing to reflected, the crimson or orange glow of the sky in the evening and the morning, as well as the red colour of the sun and moon when on the horizon, is due, on the other hand, to *transmitted* light, that is to say, to light which in its passage through great atmospheric distances, has had its blue constituents sifted out of it by repeated reflection.

"*Light proceeds in straight lines, leaving shadows where it cannot fall.*"

795. A ray or straight line of light is seen on looking at the light of the sun entering into a dark room by a small aperture, in which fine dust is floating, and seen there as a line of "motes in the sunbeam."

We cannot see round a corner. We can see through a straight tube, but not through a crooked one. The vista through a long, straight tunnel is a striking illustration of this fact, as also of the diminution of the apparent size of objects as they are more distant. If a person enter a straight canal-tunnel, two miles long, like that cut through the chalk hill between Gravesend and Rochester to join the Thames and Medway rivers (now converted into a railway), the opening at the distant end is clearly seen as a small luminous speck, having the exact form of the general arch.

In taking aim with a gun or an arrow, one is merely preparing to make the projectile go to the desired object nearly by the path along which the light comes directly from the object to the eye.

A carpenter looks along the edge of a plank to see whether it be straight.

Because light moves in straight lines, if a number of similar objects are placed in a straight line with the eye, the nearest one hides the others. In the middle of a wood or a city, a person sees completely only a few of the trees or houses that are nearest to him.

The forms of shadows prove that light moves in straight lines, for the outline of the shadow corresponds correctly with that of the object as seen from the luminous body.

The shadow of a face on a wall is a correct profile or projection.

A wheel presented edgeways to the eye appears only as a broad strip, but it seems oval or round as it is otherwise turned; so a wheel presented edgeways to the sun or other light, casts at first a straight shadow on the wall behind it, and the shadow becomes oval or round as the position is changed.

A globe, a cylinder, a cone, and a flat circle, will all throw the same round shadow on a wall, if held with their axes pointing to the luminous body, and therefore by the shadow only, these objects could not be distinguished.

A man under a vertical sun, as may be seen near the equator, stands at noon upon his own little round shadow; but as the sun declines in the afternoon, the shadow juts out on the opposite side, and at last may be so long as to extend across a field.

A distant cloud, which appears to the eye of an observer on the ground only as a streak along the sky, may yet be broad enough to shadow a whole region; for clouds generally form in level strata, and when viewed by a spectator on the ground at a distance are seen nearly edgeways.

796. A body held between a source of light and a wall, not only darkens a portion of the wall, or casts its shadow there, but makes the whole space between it and the wall a shadowed space, so that any object introduced there, is as much shadowed as the portion of the wall. A striking illustration of this is afforded when a flock of white pigeons in sunshine wheel round a tall steeple. At the moment when they enter the shadow of the steeple they seem to vanish, although there is nothing in the air between them and the eye of the spectator. Thus, also, all the planets, as they revolve about the sun, cast a long shadow beyond them or away from the sun, and when one of their satellites or moons passes where the shadow is, it suddenly disappears. The satellites or moons of Jupiter, when they suddenly disappear from the field of view of our telescopes, or are eclipsed as we term it, have generally only plunged into the shadow of the planet, and are not hidden from us by being then on the other side of its body, as many persons suppose. When our own moon is eclipsed,—a phenomenon so awful to men in the early ages of the world, she is only passing through the long shadow which the earth casts beyond itself.

797. In the case of a light-giving centre being broader than the object which casts a shadow, the shadow is less broad than the object, and terminates in a point. In the contrary case, the shadow is larger than the object, and still larger as the distance from the object is greater. When our moon passes between this earth and the broad sun, producing a total eclipse of the sun where its shadow falls, the band over which the shadow passes has to be computed, and is stated in the almanacs. Knowledge of the comparative sizes of the two globes gives the power of predicting what is to happen. The shadow of a hand held between a broad fire and the wall is small; while a small pasteboard figure of a man, placed near a narrow centre of light, like a candle, throws a shadow which is gigantic.

When the surface which receives a shadow is oblique to the direction of the light, the shadow may be much longer or broader than the object, even when the sun is throwing the light. This is seen when a narrow projecting roof, or a veranda, shadows from the high sun of a summer noon, the whole front of a house; or, as is proved by the long morning and evening shadows of trees, houses, men, and other objects, on the ground in all countries.

798. The apparent darkness of a shadow is not proportioned to its real darkness, but to the comparative strength of the surrounding lights. A landscape may be clearly seen, even when the sun is veiled by a cloud, and then little or no shadow is anywhere perceived; but as soon as the cloud passes away, deep bright lights appear where direct sunshine falls, and shadows behind every object which the direct sunbeam does not reach. Yet the objects and places then appearing dark, are in reality more illuminated than before the shadow existed, for they are receiving, and again scattering, new light from all the more intensely illuminated objects around them. A finger held between a candle and the wall, casts a shadow of a certain intensity; if another candle be then placed in the same line from the shadow, the shadow will appear much darker, although, in fact, more light will be reaching it, and reaching the eye from it, than before; it will be darker only by comparison. If the candles be separated a little sideways, so as to produce two shadows of the finger, but which coincide or overlap in one part, that part will be of double darkness, as compared with the remainders. A common mode of comparing the intensity of lights is to place them at such distances from a screen or wall, as to make them at the same time throw on the screen equally dark shadows of the same intervening object; and then, according to the law of decreasing intensity explained above, to calculate the intensities of the sources of light by the difference of their distances from the wall. The eye judges very correctly of the intensity of shadows so compared.

799. *Bunsen's Photometer.*[*]—In determining the relative illuminating power of coal-gas another method is adopted. A gas jet is burned at one end of a straight line, and a sperm candle of a certain standard quality is placed at the other end, and the space between the two is so graduated as to show how many times the one light exceeds the other in intensity. A disc of white blotting paper is rendered partly translucent by means of a solution of paraffine in benzole, the central portion of the disc remaining unchanged. This is mounted in a sliding frame, so that the light from each end can fall upon the corresponding side. So long as the lights are of unequal intensity, the opaque and translucent parts of the paper will be plainly distinguishable, but when they are equal, the difference will disappear, and the distance of the two lights from the movable screen will show their relative intensity marked off, as twelve, fifteen, twenty, or more candles. An Act of Parliament requires that a certain standard gas, tested on this principle, shall be supplied to the public. The action of the photometer depends on the fact that the paper disc presents a uniform appearance only when the light which passes through the translucent part is equal to that which is reflected by the opaque portion. Two gaslights or candles burning one at each end of the sliding scale, would show no difference in the paper when the disc was placed in the centre.

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[*] From φως, light, and μετρον, measure.

Mr. Crookes has lately applied his radiometer to photometric purposes[*] (Art. 563). The operation here depends on the deflection of a pith-bar under exposure to light. The bar is suspended in a vacuum globe, and the degrees of deflection produced by light admit of accurate measurement. A candle on each side of the apparatus keeps the index ray of light at zero. By balancing a standard candle on one side against any source of light on the other, the value of the latter, in terms of a candle, is readily shown.

800. The real darkness of a shadow, depends much on the extent and nature of the light-reflecting surfaces around it. Thus, shadows are less deep opposite to any white surface, than in other situations. An invalid lying in bed with back to the light may be saved the trouble of turning to show the countenance, by a sheet of white paper held up to act as a mirror. The reason why the moon when eclipsed—that is, as will be afterwards explained, when passing behind the earth, through the shadow cast by the earth in a direction away from the sun—becomes almost, if not quite invisible, is, that there are no other moons or bodies near our moon to reflect their light towards it. And the reason why moonless nights on earth are darker than the shadows behind a house or rock in the sunshine of day, is merely that there are then no other great bodies near the earth to reflect light into its shadow, as there are other houses and rocks near to illuminate the day-shadow of these. The moon is the only light-reflecting body of magnitude which the earth has near it; and we perceive how much less dark the earth's night-shadow is, when the moon is in a position to bear upon it.

Many persons have doubted whether the light of the moon could be, as astronomy teaches, altogether reflected light of the sun; the moon appearing to them so much more luminous than any opaque body on earth merely exposed to sunshine. They judged the so-called "lamp of night" to be as naturally self-luminous as "the lamp of day." Their error arises from contrasting the appearance of the moon while receiving direct sunshine, with that of objects on the surface of this earth, then in the darkness of the earth's shadow, which we call night. The moon when above our horizon in the day-time, is always visible from the earth to those who look for it, and is then throwing towards the earth just as much light as it does during the night; but the day-moon does not appear more luminous to human sight than any small white cloud of the same apparent breadth, so that, although visible in some part of every day except near what is called the change of moon, many persons have passed their lives without noticing it, as might happen with respect to a candle burning in the open air at noon. The full moon gives to the earth only about a one-hundred-thousandth part as much light as the sun. That it is not self-luminous, but that it reflects the light which it receives from the sun is proved by the fact that the light is polarized. (See *Polarization of Light.*)

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[*] For a description of his process the reader is referred to 'Nature, March 16, 1876, p. 391.

"*Light moves with extraordinary velocity, which, however, has been calculated.*"

801. The great precision with which the astronomical skill of modern times, enables men to foretell the instants of remarkable occurrences or changes among the heavenly bodies, has served for the detection of the fact, that light is not an instantaneous communication between distant objects and the eye, as was formerly believed, but is a messenger which requires time to travel: and the rate of the travelling has been ascertained. If the interval between two successive eclipses of the satellites or moons of the planet Jupiter be observed when the planet is on the same side of the sun with the earth, and all the subsequent instants of eclipse calculated therefrom, it is found that when Jupiter is on the opposite side of the sun from our earth, the eclipses occur about 16½ minutes later than the calculated times. At intermediate situations, the difference between the observed and the calculated times diminishes proportionally, and when Jupiter comes once more into conjunction with the earth, the times agree exactly. This discrepancy can only be explained on the hypothesis that light requires 16½ minutes to travel across the earth's orbit, or 8¼ minutes to come to us from the sun. This immense velocity may perhaps be better appreciated by stating that light would traverse a space equal to the whole circumference of our globe in the eighth part of a second!

The sun's light reflected from the moon is estimated to reach the earth in a second and a quarter. As the planet Jupiter is five times as distant from the sun as the earth, the light, by which he is seen from the earth, must have left the planet at least forty minutes before, and it would require four hours for light to reach us from the remote planet Neptune. In spite of this great velocity, it is calculated that the light of the nearest fixed star would require at least *three years* to reach the earth, and it might occupy *centuries* in coming from the nearest nebula, so that we should see the star and nebula by the lights which emanated from them years and centuries ago.*

802. The velocity of light, ascertained by the method above described, is so marvellous, about 192,000 miles in a second, that the philosophic Dr. Hooke, when the assertion was first made by the Danish astronomer Roemer, in 1676, said he could more easily believe the passage to be absolutely instantaneous, even for any distance, than that there should be a progressive movement so prodigiously rapid. The truth, however, is now put beyond doubt, not only by numerous other facts bearing upon the subject, but also by direct experiment. This feat was accomplished, in 1849, by the French philosopher M. Fizeau, who determined the time taken by a beam of light to travel from Suresnes to Montmartre and back again by reflection, a distance of eleven miles. His contrivance consisted essentially of a wheel, with 720 teeth, which could be rotated with a very high velocity. When a sufficient speed of rotation had been attained he found that a beam of light which passed through one interval of the toothed wheel returned after reflection at the distant station, not through the same interval but through the next one. Before the light had travelled eleven miles, therefore, the wheel had turned through the space of one tooth. The velocity of the wheel being shown by an indicator, the velocity of light was easily found. Fizeau thus calculated it to be about 194,000 miles in a second.

All ordinary phenomena upon earth may be considered as happening at the very instant when the eye perceives them, the difference of time being too small to be appreciated. It is therefore not sensibly incorrect, when we are measuring the velocity of sound, by observing the time between the flash and the report of a cannon fired, to assume that the event takes place at the very moment when the eye notes it. The speed of light and of the electric impulsé are found to be nearly the same, and the public mind, now familiar with the prodigies of the electric telegraph, is less astonished than it was two centuries ago.

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* Pouillet, in considering this subject, says that the nearest star cannot be at a less distance than 200,000 times the distance of the earth from the sun. Hence, light in issuing from this star, would require for its passage 200,000 times 8′ 13″, *i.e.*, 1141 days or three years and forty-five days. It is not unreasonable to suppose that we see stars a hundred thousand times more remote, and that many centuries might elapse before the light from these reached our earth.

"Light passes readily through some bodies—which are therefore called transparent; but when it enters or leaves their surfaces obliquely, its course is bent."

803. It is very remarkable that light is able to dart readily and in every direction through great masses of solid matter, such as thick plates of glass, blocks of rock crystal, and mountains of ice; while a mere film of another substance may suffice to obstruct it. The reason we cannot yet explain, but we perceive that the arrangement of the particles of the mass, has more influence than their peculiar nature. Nothing is more opaque than masses of the metals, but all these become quite transparent when held suspended in liquids, or when forming part of a coloured glass. Thus gold is opaque in substance, but when separated from its solution by phosphorus the metal is so finely reduced that it becomes quite transparent, forming a clear, ruby-coloured liquid with water (Art. 2, p. 2). When diffused through glass by fusion, metallic gold imparts to it that splendid transparent ruby colour, which is so much admired in some varieties of Bohemian glass.

Bodies which allow objects to be seen through them are called *transparent.* This property is possessed by glass, water, and air. Those which cut off the light completely and prevent substances from being seen through them are called *opaque.* Others which allow light to be transmitted, but which prevent the forms of bodies from being distinctly seen through them, are called *translucent*—such as ground glass and oiled paper.

No substances are, however, absolutely opaque, and none perfectly transparent. Gold itself, which is one of the densest metals, when hammered into very thin leaves, allows a feeble green light to pass through it, and when alloyed with a small proportion of silver, the light which traverses the metal is of a rich purple colour. As the thickness of the leaves is only the 300,000th of an inch, it follows that light penetrates gold at least to this depth.

The purest water and air arrest a part of the light which enters them. Miller states that a column of the clearest water seven feet in depth arrests one half of the light which falls upon it. The light which traverses it has a bluish-green tint. This has been employed as a test of purity: the water is examined by a good light through a glass tube of this length enclosed in a metal tube, the two ends being closed with plate glass. If the water is impure very little light passes, and it differs in colour. Pure air also arrests light. Thus, when the light of the sun traverses a great extent of atmosphere in a slanting direction—as shortly after sunrise or before sunset—a considerable portion is absorbed and lost. Dr. Young estimated that the light of the sun passing horizontally through about two hundred miles of air possessed only the two-thousandth part of its original intensity.

REFRACTION OF LIGHT.

804. Light having once entered any transparent mass of uniform or homogeneous nature, passes forward in it as straightly as in a vacuum ; but at the surface, whether on entering or leaving it, if the passage be oblique, and if the mass be of a different density or nature from the other transparent medium in contact with it, a very curious and most important phenomenon occurs, namely, the light suffers a degree of bending from its previous direction proportioned to the obliquity. Such bending is technically called REFRACTION. Light passing from air directly or perpendicularly into water, glass, or any such transparent body, suffers not the least bending or deviation from its course. A ray, for instance, passing from air in the direction, *a c*, into a piece of glass, *g h* fig. 186), would reach directly across to the points, *o* and *b* ; but if the ray fall slantingly or obliquely, as along *d c*, then, instead of continuing along *c i k*, in its first direction, it is at the moment of entering the new medium bent into a path, *c e*, nearer to *c o*, the perpendicular to the surface at the point of entrance. Moving straightly while in the substance of the glass, it is bent, on passing out again at *e*, just as much as at first, but in the contrary direction, or away from the perpendicular at that surface, *viz.*, into the line, *e f*, instead of *e n*. A ray, therefore, passing obliquely through a transparent body with parallel surfaces, has its course shifted a little to one side of the original course, but still proceeds in the same direction, or in a line parallel to the first—as here shown in the line, *e f*, parallel and near to the line, *i k*. If the surfaces of the transparent body are not parallel to each other, the ray is otherwise bent, as will be explained in coming pages.

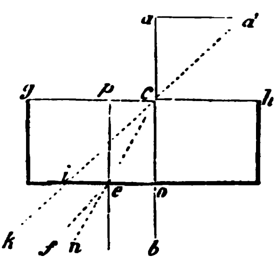

Fig. 186.

The degree of this bending or refraction of light is measured by comparing the obliquity of its approach to the surface, called *the angle of incidence*, *d c a*, with the obliquity of its departure beyond, called *the angle of refraction*, *e c o*. If the degrees of obliquity of the incident and refracted rays from the normal or perpendicular line, *a c b*, be estimated by the perpendicular distances, *d a* and *e o*, of points *d* and *e*, equally distant from *c*, it is found that the directions of the original and bent rays so estimated, always bear some invariable relation to each other for the same media. This constant relation is termed the *index of refraction*.

805. Thus when light passes obliquely from air into water, the line, *a d*, measuring the obliquity before refraction, is always longer than the line, *o e*, measuring it after refraction, as the number four to three, and the refraction index of water is therefore said to be $\frac{4}{3}$. Common glass has the greater refraction index $\frac{3}{2}$, and so on, for other substances. It is important to remark, that for the same substances the same relation always holds, whatever the obliquity of the incidence may be.

The following table shows the refractive powers of some well-known solids and liquids, the light being supposed to pass from atmospheric air. From this it will be seen that the diamond occupies the highest place :—

Diamond	2·44	Crown glass	1·53
Phosphorus	2·22	Alcohol	1·37
Flint glass	1·60	Ether	1·35
Rock salt	1·55	Water	1·33
Quartz	1·54	Ice	1·30

As a general rule, the refractive powers of transparent media increase with their densities. It increases, for instance, through this list—air, water, salt, and glass. Newton, while engaged in his experiments upon this subject, observed that *combustible* bodies had a greater refractive power than corresponds to their density, and he then with singular sagacity hazarded the conjecture, which chemistry has since remarkably verified, that diamond and water both contained combustible ingredients. We now know that diamond is merely crystallized carbon, and that water is composed of hydrogen, an inflammable gas, and oxygen. Diamond has the greatest light-bending power of any known substances, and to this it owes in part its sparkling brilliancy as a jewel. In consequence of this high refracting power of the diamond, the total reflection of light commences at small angles of incidence, a property which adds greatly to its lustre.

Melted phosphorus, naphtha, and sulphide of carbon have a high refracting power on light. The latter is the most refractive liquid known. These are all very inflammable substances. In the last-mentioned liquid, carbon is liquefied in its combination with sulphur. Two combustible substances are here associated, and the refracting power on light is proportionally greater. Its dispersive power is also great. It shares these properties in common with the diamond, and in fact it may be looked upon as liquid diamond.

806. The old explanation, which may be retained to aid popular conception of this phenomenon, was that it is due to an attraction between the light and the refracting denser medium. The light approaching from *d* to *c*, for instance (fig. 186), behaves as if attracted by the solid body below it, and is bent into the direction, *c e*; and, again, on leaving the body, as if equally attracted and bent back again, it takes the direction, *e f*, instead of *e n*; the attraction and bending being greater, the greater the obliquity.

The following are familiar examples of this bending of light in passing from one medium to another :—

If an empty vessel, *b c f e* (fig. 187), be in the sun's light, so that the rays falling within it may reach low on the side, as from *a* to *d*, but not to the bottom, then, on filling the vessel with water, the sun will be found to be shining on the bottom or down to *e*, as well as on the side. The reason of this phenomenon is, that water being a denser and more refracting medium than air, the light, on entering it at *c*, is bent towards the perpendicular (*c f*), at the point of incidence, and reaches the bottom. So again, if a coin or pebble were laid on the bottom of such a vessel at *e*, it would not, while the vessel was empty, be seen by an eye at *a*, but would be visible there immediately on the vessel being filled with water; for then the light leaving the coin in the direction of *e c*, towards the edge of the vessel, would, at *c*, on passing from the water into air, be bent away from the perpendicular, and instead of going to *g*, would reach the eye at *a*. The coin, moreover, would appear to the eye to be in the direction, *c d*, higher up, instead of in the true direction, *c e*, low down : for the eye not being able to discover that the light had been bent in its course, would judge the object to be in the line by which the light arrived.

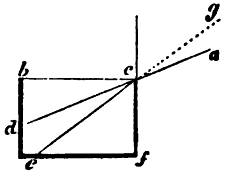

Fig. 187.

807. It is thus that objects at the bottom of water, when viewed obliquely, do not appear so low as they really are, and that a person viewing the bottom of a river or pond, or any clear water from its bank, naturally judges its depth to be much less than it really is. A person, if looking from a boat directly down upon objects at the bottom, sees them in their true directions, but even then not quite at their true distances, as will be afterwards explained; but if he view them more and more obliquely, the appearance becomes more and more deceptive, until at last it may represent them as being at even less than half of their true depth.

An incident witnessed by the writer may be mentioned in illustration. In crossing the Chinese Sea, where no danger was apprehended, an alarm was suddenly given that the ship was among rocks. Through water singularly clear, coral rocks were visible all around and at no great distance; some of them seemed to approach the surface of the water. The sails were instantly backed and soundings were taken, which proved the depth to be greater than appeared.

On account of this bending of light from objects under water, there is more difficulty in hitting them with a bullet or spear. The aim by a person not directly over a fish, must be made towards a point apparently below it, otherwise the weapon will miss by flying too high. The spear sometimes used in this country for killing salmon, is a weapon employed among the islanders of the Southern Ocean for killing the albacore.

The bending of light, when passing obliquely from water, explains the following facts. A straight rod or stick, of which a portion is immersed obliquely in water, appears crooked at the surface of the water, the portion immersed seeming to be bent upwards. That part of a ship or boat visible under water appears much flatter or not so deep as it really is. A deep bodied fish seen near the surface of water, appears almost a flat fish. A round body there appears oval. To see bodies under water, in their true directions and nearly of their true proportions, the eye must view them through a tube, of which the lower end, closed with plate-glass, is held in the water or through the upright sides of containing vessels formed of plate-glass, now common in aquariums.

808. Gases have, like solids and liquids, a power of refracting light, and, as with solids, those which are most inflammable or combustible possess this power in the highest degree. Hydrogen has the highest, and oxygen the lowest refracting power, the numbers indicative of this being respectively 6614 and 861, air being taken at 1000.

Each compound gas has its own definite power of refracting light, but mixtures of gases have a power depending on the proportions of their ingredients. Thus the refracting power of air, taken at 1000, corresponds to that of a mixture of four parts of nitrogen with one of oxygen.

As light is refracted on passing obliquely from air into water, glass, or any other substance denser than air, so also is it bent on coming from empty space into the ocean of our atmosphere. Hence none of the heavenly bodies, except when directly over our heads, are seen by us in their true situations. They all appear a little higher than they really are, and the more so the nearer they are to the horizon. To a spectator at *d* (fig. 188), supposed to be on the surface of the earth, a star really at A appears to be at *a*, because its rays, on reaching the atmosphere at *c*, are bent downwards. In astronomical books there is always given a table of refractions, showing what correction must be made on this account for different apparent altitudes. Thus our atmosphere bends the rays of the sun so that we see him in the morning a little while before he is really above the horizon, and we see him in the evening a little while after he is really below it, and thus lengthens the day; for the rays coming horizontally from *e* to *d* appear to come from *b*, although in truth it comes from the lower situation, B, and is bent into the level line only at *e*. As the atmosphere is denser near the surface of the earth than higher up, the light is more and more bent as it descends, and hence it describes a course which is gently curved, and therefore unlike the course of light in incompressible water.

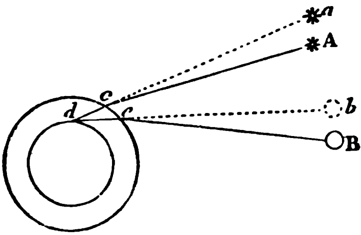

Fig. 188.

809. Certain states of the atmosphere, depending chiefly on its humidity and warmth, change very considerably its ordinary refractive power; hence, in one state a distant hill or island may be just visible over an intervening eminence of land, and in other states, the same object will be seen high above, or it may have disappeared altogether.

An interesting phenomenon, due to refraction, is often observable in a day of warm sunshine. Black or dark-coloured substances, by absorbing much light and heat from the sun's rays, warm the air in contact with them, and make it dilate and rise in the surrounding air, as oil rises in water. The light then from more distant objects, reaching the eye through the rarefied medium, is bent a little; and owing to the heated air rising irregularly under the influence of the wind and other causes, many objects seem to have a tremulous or a dancing motion. The same phenomenon is to be observed at any time, by looking at an object beyond the top of a chimney from which hot air without smoke is rising.

This bending of light by the varying states of the atmosphere, renders necessary the frequent repetition of geometrical observations made in the measuring of heights or of base-lines for the construction of maps and charts.

810. *Mirage.*—It is to a somewhat similar effect that the phenomenon of the *Mirage* may be assigned; but in this case there is reflection as well as refraction. Travellers in their journeys across the desert have occasionally seen inverted images of palm-trees, rocks, and other objects, as if reflected from a smooth surface of water between them and the objects. They appeared to be within reach of a beautiful lake; but as they approached the spot, the whole vanished.

The explanation of this phenomenon is that the strata of air immediately above the heated sandy soil, are greatly expanded and rarer than the strata above them, which, in spite of the law of diffusion (Art. 459), remain denser. Rays of light proceeding from objects in a direction a little above the level of the earth, and nearly parallel to it, meet the heated and rarer strata at a very obtuse angle. They take the course of a curve as the result of gradual refraction, until at length the angle of incidence, which goes on increasing, reaches the point at which refraction is changed into reflection, and the rays meet the eye of the spectator as if proceeding from an object below the level of the earth. This gives to it the appearance as if it was reflected from the surface of water.

The annexed engraving (fig. 189) will show how the strata of air in contact with the heated soil produce this change in the direction of the rays of light, and thus cause an optical illusion. Rays from the palm-tree pass directly to the eye of the spectator, A, in the line, P H. The tree is thus seen in its natural position in the dense portion of the atmosphere. The heated strata are represented by the letters C C, in contact with the surface of the earth, B, increasing in density as they ascend. A ray of light proceeding from H begins to undergo refraction at I. This is increased as it passes through the lower strata, K L, until it reaches M, where the angle of incidence is so small that it is reflected, and traversing N and O by refraction, it meets the eye of the spectator, A, at P. According to the law of visual direction, the object from which the light proceeds is seen inverted in the direction of the line, P O Z. It therefore appears to the spectator as a perfectly reflected image, and conveys the impression that it is a reflection from the smooth surface of water.

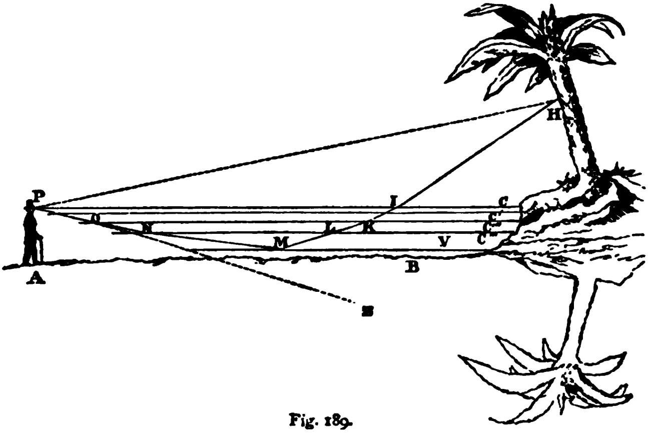

Fig. 189.

The *Fata Morgana*, observed occasionally on the coast of Sicily, may be explained on similar principles.

These optical phenomena are not confined to warm climates. They have been observed in the Arctic regions. Scoresby noticed on the coast of Greenland that in certain states of the atmosphere the rocks appeared to be inverted and refracted in a symmetrical form, appearing like ruined castles, obelisks, and monuments, some of them surmounted by turrets, battlements, and towers, while in other cases large masses of rock were apparently suspended in the air at a great height above the summits of the mountains to which they referred. These effects were no doubt due to refraction.

On one occasion, in 1822, Mr. Scoresby saw, off this coast, the inverted figure of a ship in the air. By the aid of a telescope, he was able to discover that it was his father's ship, which was at the time below the horizon. This opinion proved correct. At the time of the observation the ships were thirty miles apart. As in atmospheric refraction, objects appear raised above their true position, owing to the bending of the rays of light in passing from a rarer to a dense medium.

811. As it is the obliquity with which a ray meets the surface which, in any case of refraction, determines the degree of bending, a body, seen through a medium of irregular surface, appears so distorted as not to be recognizable. It is because the two surfaces of ordinary window-glass are not, as in the case of plate-glass, perfect planes, and parallel to each other, that objects seen through a common window, appear generally more or less out of shape. Hence the beauty and utility of plate-glass windows, now in general use.

The refraction or bending of light is most interestingly exemplified by the effect of a prism-shaped piece of glass, a cross section of which is represented in fig. 190. A ray from *a*, entering the prism at *b*, is there bent *towards* the internal perpendicular, and takes the direction, *b c*, then on emerging again at *c*, it is bent *away* from the external perpendicular, and thus with its first deviation doubled, goes on to *d*.

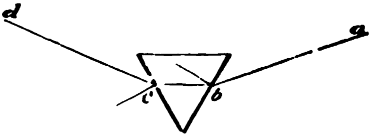

Fig. 190.

The law of refraction is well illustrated by what is called *a multiplying glass*, that is to say, a flat piece of glass, *a b c* (fig. 191), having many distinct faces cut upon it at angles with each other. If any small object, a coloured bead for instance, be placed at *d*,

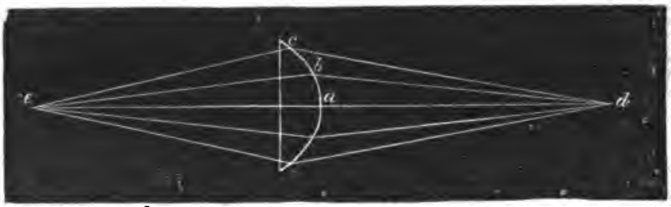

Fig. 191.

an eye at *e* will see as many beads as there are distinct surfaces or faces on the glass; for, first, the light, *d a*, passing perpendicularly, and therefore straight through, will form an image as if no glass intervened; then the rays from *d* to the surface, *b*, will be bent by the oblique surface, and will show the object as if it were in the direction, *b e*; and the light falling on the still more oblique surface, *c*, will be still more bent, and will reach the eye in the direction, *c e*, exhibiting a similar object also in that direction—and so of all the other surfaces. If the eye were at *d*, and the object at *e*, the result would still be the same. A plate of glass roughened, or cut into cross furrows, becomes an effectual screen or window-blind, by disturbing the passage of light through it so that the objects beyond it are not distinguishable.

> "*A beam of white light thus refracted is resolved into beams of the seven so-called primary colours seen in the rainbow*; *which, on being again collected and blended, become white light as before.*"

812. It is a very singular fact connected with the bending or refraction of light, that a beam of pure white light from the sun admitted into a darkened room by a small opening in the window-shutter, and made to pass through a prism, instead of bending all together and appearing still as the same white light, is divided into many beams, which, falling on the white wall, are seen to be of different and most vivid colours. This solar *spectrum*, as it is called, formed upon a screen, consists of an endless variety of tints of colour, of which the seven in the figure are the most prominent, shading into each other imperceptibly. That these coloured rays are really the components of the original white beam, is proved in several ways. First, if the seven colours which appear in the spectrum be painted separately round the rim of a wheel, and the wheel be then turned rapidly, the individual colours cease to be distinguished, and only a white band appears. Second, if the rays

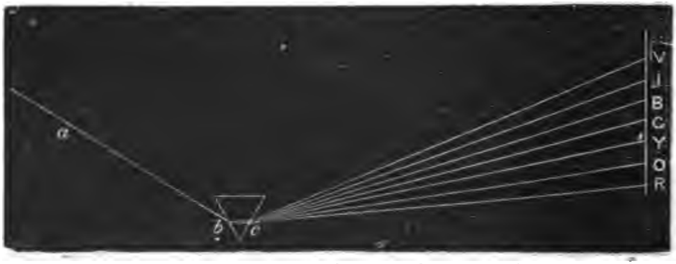

Fig. 192.—V, Violet. I, Indigo. B, Blue. G, Green. Y, Yellow. O, Orange. R, Red.

of the spectrum produced by a prism be again gathered together by another prism reversed, or by a lens, they reproduce white light as before.

According to Sir D. Brewster, the seven are resolvable into three primary colours,—blue, yellow, and red, the green, orange, and violet being compounds of these primary colours. There is a difficulty in admitting this theory in the fact that when the compound colours are separately passed through another prism they are not resolved into the primary. Thus green remains green and cannot be decomposed into blue and yellow.

If we mix together two coloured substances very finely powdered, one blue and the other red, the mixture will have a purple or violet tint, the differently coloured particles being no longer distinguishable. On examining the coloured powder with a prism, it will be separated into two distinct powders, one red and the other blue.

Green tea owes its colour generally not to any green colouring matter, but to a mixture of Prussian blue and a yellow colouring substance in very fine powder. The naked eye perceives only the green tint, but the separate colouring matters may be distinguished by the aid of a microscope.

The following experiment shows that the sensation produced on the eye by the two component colours may be the same as if the compound colour issued from the object. If a tube containing a yellow liquid (a weak solution of the acid chromate of potassium) is immersed in a jar containing a blue liquid (sulphate of copper), and the jar held opposite the light, the eye will perceive at one time the two primary colours, blue and yellow, and the compound colour, green, in the immersed tube.

Mr. Clark Maxwell has furnished an explanation of this curious experiment. He has proved that this yellow solution cuts off the blue end of the spectrum, leaving only the red, orange, yellow, and green, while the blue solution cuts off the red end, leaving the green, blue, and violet. Hence, the green rays only pass through both, all the other rays being absorbed or quenched by one or the other solution.

813. When Newton first made known the phenomenon of the many-coloured spectrum, and some of the extraordinary conclusions to which it led, great surprise was universally excited, for the common conception of unmixed purity was that of white light. The extension and importance which subsequent researches have given to the prismatic decomposition of light, are so great that we must return to this experiment and its consequences, at a later part of the section.

All transparent substances, when bending light strongly, produce more or less a separation of colour; but it is an important fact, that the quality of merely bending a beam, or of *refraction*, and that of dividing it into coloured beams, or of *dispersion*, are distinct qualities, not having the same proportion to each other in different substances. As a general rule, the length of the spectrum under prisms of equal angles, serves to determine the relative amount of dispersive power in transparent bodies. Sulphide of carbon has a highly dispersive as well as refractive power. When used as a prism, it produces a perfect spectrum on a large scale, with a splendid array of colours. The prismatic colours are frequently produced by the light traversing the glass bottle in which this liquid is contained. Newton, from not being aware of this difference in the refractive and dispersive powers of bodies, concluded that a perfect large refracting telescope could never be made: he assumed that the bent light would always be coloured, and so would render the images indistinct. We now know, however, that by uniting lenses of two or more kinds of glass, we may obtain the requisite bending of light without dispersion. This very important discovery was made by the eminent optician Dollond, the first maker of the achromatic telescope.

The diversified colours of the substances in nature depend upon their fitness, from texture or other peculiarity, to reflect or transmit certain modifications of common light; the different colours not being parts of the body itself. We have to explain in a future page that the vivid colours of the rainbow are merely the white light of the sun, reflected to us after being refracted and modified by the transparent drops of falling rain, and that the sparkling appearance of rubies and emeralds, which we see in a cut-glass lustre, is a phenomenon of the same kind; and we shall learn that by scratching the surface of a piece of metal so as to have a given number of fine lines in a given space, as mother-of-pearl shell has, we can cause the same substance to appear in splendid iridescent colours.

> "*To transparent substances, as glass, such form may be given as to cause all the rays of light which pass through them from any one point, to converge or bend so as to meet again in another corresponding point beyond them and pass onwards,—the body itself, from the required shape*

generally resembling that of a flat bean or lentil, being then called a LENS."

814. The rays of light issuing from any point, *c*, towards any surface, *a b*, are said to form a cone or *pencil* of diverging light. It is evident that to make all such rays converge or meet again in one place, as *f*, beyond the transparent body, *a b*, it would be necessary, while the middle ray or axis of the pencil, *c d f*, did not bend at all, for the others to be bent more and more, in proportion as they fell upon the body farther and farther from the centre, *d*. A *lens*, or glass, of which the surface is ground, to have a regular convexity or bulging, as if it were a portion cut off from the surface of a ball or sphere, possesses the property of so converging or collecting the rays to a point. In fig. 193, *a b* is such a glass, similarly ground on both sides; the ray, *c d*, falling on its middle, goes straight through to *f*; the oblique ray, *c e*, is bent down a little, first, on entering the surface at *e*, and then as much more on leaving the opposite surface with equal obliquity, and so arrives at *f*; the ray, *c a*, for corresponding reasons, is still more bent, and equally arrives at *f*;—and similarly for any other rays that might be examined. The point, *f*, is usually called a *focus* (the Latin for *fire-place*), because when the light of the sun is thus gathered, the heat concentrated with it is powerful enough to set combustibles on fire. Oblique pencils, as form *o* and *x*, have a focus similarly determined: it always lies in

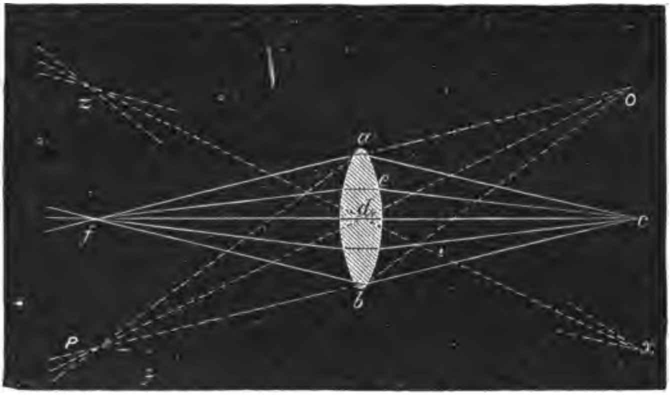

Fig. 193.

the line joining the origin of the luminous pencil with the centre of the lens. It is important to understand here that rays of light meeting at any focal point in the air or in any other transparent medium, do not at all disturb one another like solid masses clashing, but simply cross and pass onwards, as sketched here at letters *z*, *f*, *p*.

815. Lenses are of different shapes, as represented in fig. 194. That marked 1, having both sides convex, is called *a double convex lens*. A glass convex only on one side, and plane or flat on the other, as 2, does as effectually gather the rays, but with half the power, and the point of meeting, or focus, is therefore proportionately more distant. Such a glass is called a *plano-convex lens.* Then the gathering or converging power of any glass, whether doubly or singly convex, is in proportion to the degree of its convexity or the bulging of the surfaces, for the less it bulges, the more nearly does it approach to being a plane glass, and the more it bulges, the more obliquely will the rays. at any distance from the centre, fall upon its surface, and the sooner, therefore, in consequence of their being more bent, will they all meet the axis-ray to form a focus;—hence No. 1 would converge much more quickly than No. 3, which represents nearly a common spectacle glass; and a very minute globe is the form most powerfully converging of all. The surfaces of No. 1 are portions of a small globe; those of No. 3 are smaller comparative portions of a globe much larger. Concave lenses, as No. 4, which is a *double concave*, and No. 5, which is a *plano-concave* lens, in obedience to the same law of refraction, spread rays, or bend them away from the axis of the pencil, in the same degree that similarly convex lenses gather them. A concave lens, therefore, receiving the converging pencil of rays from a convex lens, might restore them to their former nearly parallel direction. Very useful purposes, as will be afterwards explained, are served in optics, by certain combinations of differently formed lenses. A lens may be

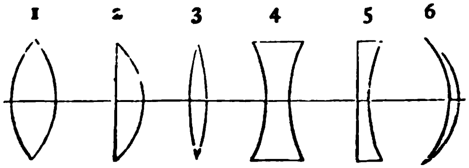

Fig. 194.

convex on one side and concave on the other, as at No. 6, called a *meniscus* lens, because it resembles the crescent moon, and its effect will be according to the curve which predominates.

A person recollecting the case of the "multiplying glass," described at page 581, might say,—but is not a convex lens merely a multiplying glass of a much greater number of faces, and if so, why, instead of one image, does it not make thousands? The answer is, that the multiplying glass, by every face, bends *a set* of rays, capable of forming a distinct and complete image; but the lens has no surface large enough to bend more than single rays, it concentrates all into focal points, which form a general image of great vividness and beauty.

> "*When the light proceeding towards a lens from every point of an object placed before it, is collected in corresponding points behind it, a perfect image of the object is there produced. The* CAMERA OBSCURA, *the* SOLAR MICROSCOPE, *and the* MAGIC LANTERN *are merely arrangements whereby an image so formed is received upon a suitable white surface in a dark place.*"

816. If a lens, such as a common spectacle glass, *a* (fig. 195), be placed to fill up an opening made in the window-shutter of a darkened room, then, from any object before that opening—as the cross here represented, all the light which different points radiate towards the lens will be concentrated or gathered together in corresponding focal points behind the lens within the room, and if a sheet of paper be held there at the distance of the focal points, a beautiful inverted image of the object will be seen upon the paper.

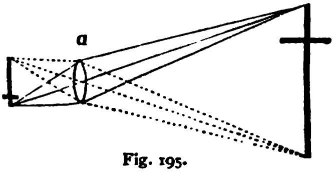

Fig. 195.

In these few words, we have described that most interesting arrangement called the *Camera obscura* or *dark chamber;* and when a lens is chosen of proper size and focal distance, and a screen, or the wall of the chamber (if at the required distance), is properly prepared to receive the light, the most admirable portraiture is instantly produced of the whole scene which the window commands.

817. It appears in fig. 195 that the image, formed beyond a lens by the gathered light, is in an inverted position, for the light from the top of the object darts through the opening or glass in a descending direction, and that from the bottom rises to the opening, and in the same direction passes beyond it. It is necessary, therefore, in a camera obscura, to place a small mirror diagonally behind the lens, so as to throw all the light which enters, downwards to a broad table, upon which the picture may be conveniently contemplated from any side.

The camera obscura gives useful assistance to young painters, by enabling them to study perspective outlines and the effects of light, shade, and colour, more profitably than they can at first, by looking at the objects themselves.

The modern art of *Photography* (which means writing by light) fixes the otherwise transient image upon the screen of the camera. This is effected by coating the screen of the camera with a chemical preparation sensitive to light. The discovery made by Daguerre, in 1830, has proved to be one of the most glorious in the whole domain of science. This subject will be again noticed under the chemistry of light.

A similar but less vivid effect is produced by merely making a small hole in the shutter of a dark room, and letting the light which enters by it fall on any white surface beyond. The whole landscape is at once dimly portrayed upon the surface. Barry, the eminent painter, while lying on a sick bed, in fever, mistook such a scene appearing on the ceiling of his room for a supernatural vision. If the opening be very small, the picture will be tolerably defined, but very feebly illuminated : but if the opening be of considerable size, the mixing of the pencils will be so great as to leave no particular object distinguishable. In either case, however, if a lens be introduced to fill the opening, it will converge every entering pencil of light to an exact point, and a perfect picture instantly starts into view.

818. The distance from a lens at which an image is formed, or the *focal distance*, depends, first, upon the refractive or bending power of the lens, that is, on its form and substance; and, secondly, upon the direction of the rays of light when they reach the lens, as to whether they are divergent, parallel, or convergent.

Rays diverging from a point, *a* (fig. 196), to fall on a comparatively flat or weak lens at L, might meet only at the point, *d*, or even further off; while, with a stronger or more convex lens, they might meet at *c* or at *b*. A lens weaker still might only destroy the divergence of the rays, without being able to give them any convergence at all,—and then they would all proceed parallel to one another, as seen at *e* and *f*. If the lens were yet weaker, it might only destroy a part of the divergence, causing the rays from *a*, after passing through, to go to *g* and *h*, instead of to *i* and *k*, in their original direction.

In an analogous manner, light coming to the lens in the contrary directions from *b*, *c*, *d*, &c., might, according to the strength of the lens, be all made to come to a focus at *a* or at *l*, or in some more distant point; or the rays might become parallel, as *m* and *n*, and therefore would never come to a focus, or they might remain divergent.

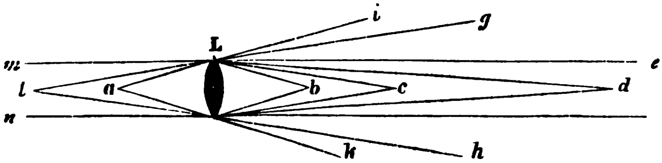

Fig. 196.

It may be observed in the above figure (196), that the farther an object is from the lens, the less divergent the rays are which fall from it upon the lens; or the more nearly do they approach to being parallel. Proceeding from *b*, there is much divergence in the exterior rays, from *c* less, from *d* less still, and rays from a great distance, as those represented by *e* and *f*, appear quite parallel. If the distance of the radiant point be very great, they really are so nearly parallel that a very nice test is required to detect the non-accordance. Rays, for instance, coming to the earth from the sun, do not diverge the thousandth of an inch in a thousand miles. Hence where we wish to make experiments with parallel rays, we take those of the sun.

Any two points so situated on the opposite sides of a lens, as that, when either becomes the radiant point of light, the other is the focus of such light, are called *conjugate foci*. An object and the image of it formed by a lens are always in *conjugate foci*, and as the one is nearer the lens, the other will be in a certain proportion more distant.

819. The *principal focus* of a lens, by the distance of which from the glass we compare or classify lenses, is the point at which the sun's rays, or any parallel rays, are made by it to meet; and thus, by holding the lens in the sun, and noting at what distance behind it, the little image of the sun is most clearly defined, we can at once ascertain the focus or focal length of a glass.

It is remarkable that the refractive power of the common glass used for lenses is such, that the focus of a double convex lens is just as distant from it as the centre of the sphere, of which its surface is a portion. This gives another fact with which to associate the recollection that the focus is nearer as the convexity of the lens is greater, that is to say, as the surface is a portion of a smaller sphere. It may also be proved both by calculation and experiment that if a lens be held at twice its principal focal distance from a candle—suppose at *c* for a lens with the focus at *a* (fig. 196)—the image of the candle will be formed at *l* just as far on the other side. Thus, then, by trying with a lens until the image of a candle is formed at the same distance from it as that at which the candle stands, we have a second mode of ascertaining the focal distance of a lens, or the degree of its convexity. Other kinds of glass and other substances refract with different power; but the facts now stated should be retained in the memory as standards of comparison.

Because the focal point of light passing through a lens is at the same distance from the centre of the lens, in whatever direction the light passes through, a surface placed to receive the picture of a broad field should really be concave, that is to say, all parts of it should be nearly at the same distance from the centre of the lens, otherwise the image will be more perfect either at its middle than towards its edges, or the contrary—but it is not found necessary to attend to this in common practice, when the object and its image are not of great extent.

820. The size of an image formed behind a lens is always proportioned to the distance of the image from the lens, and the image is as much larger or smaller than the object, as it is farther from or nearer to the lens than the object is. This will be evident from considering the figure (197), in which *c* represents the place of a lens, and the lens, according to its power, will form an image of the cross, *a b*, in some situation, as at *d*, *e*, or *g*. Now wherever the image is formed, and by whatever lens, one end of it must be in contact with the line, *a g*, and the other

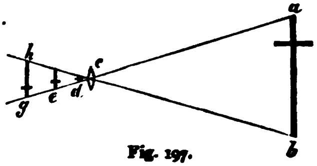

Fig. 197.

end with the line, *b k*; and as these lines cross each other at *c*, and widen regularly afterwards, a line joining them (and the image is such a line), must always be shorter the nearer it is to *c*, that is to say, shorter in proportion to the converging power or focal distance of the lens.

The narrow luminous circle called the focus of a burning-glass, is really but the image or picture of the sun formed by that glass or lens. The intensity of the heat and of the light is of course in proportion as the image is smaller than the glass which forms it, and the nearer that the image is formed to the lens, or the more powerfully convergent that the lens is, the smaller will the image be. Mr. Parker's famous burning lens, which cost £700, and became the property of the Emperor of China, was three feet in diameter, and the diameter of the sun's image formed by it was one inch: it concentrated the light and heat therefore about 1,300 times. To render the effect still more powerful, a smaller lens was placed behind the larger, further reducing the size of the focal image. Surprising effects were produced by this lens, in the melting of metals, inflaming of combustibles, &c. The size of burning lenses, formerly, was limited by the difficulty of obtaining the great masses of glass required to form them; but glasses have since been built up of many pieces suitably united together. Some large lenses have been made of water, that is, of water inclosed between capacious glasses, formed like watch-glasses. A common spherical goblet of water, or a vase for holding gold-fishes, has in some cases acted as a burning-glass, setting fire to window-curtains, near to which it had been left in the sunshine.

821. The nearer an object is brought to a lens, the more distant, and therefore the larger, will the image formed by it become; for, as the rays falling upon a lens are divergent in proportion to the nearness of the object, and therefore with the same power of lens, must meet farther behind (as seen in fig. 197), so the axes of the sets of rays, as the lines, *c a* and *c b*, will be separated farther before the rays meet, and will have made the image proportionally larger. If we suppose the cross, *d*, in the same diagram to be the object, its image would be *a b*. The sun is exactly as much larger than his image formed by a burning-glass, as he is more distant from it than the image.

From these considerations it follows that, in a camera obscura, the screen should, for distant objects, be at the distance of its principal focus from the lens, and a little farther off than this for near objects. The lens is usually fixed in a sliding piece, which allows the distance from the screen to be adjusted to circumstances. If the representation be desired large, the lens must be of a long focus · if small, the lens must be of a short focus. Again, when by the reversed use of the lens, a small object, as *d*, is to be magnified on a screen or in the air to such a size as *a b*, then the object must be placed but a little beyond the principal focus of the glass; if it be placed nearer, the pencils of rays from it would never be gathered to focal points at all, and no image would be formed at any distance.

When, as supposed in the last sentence, a small object is placed very near a strong lens, and the image is thrown upon the wall of a dark room, perhaps a hundred times farther from the lens than the object is, the image is a greatly magnified representation of the object, *viz.*, it is a hundred times longer and a hundred times broader, and therefore has ten thousand times as much surface as the object. If, in such an experiment, the object be illumined only in an ordinary degree, the light, being diffused or diluted in the same degree as the image is enlarged, is too faint to suffice for distinct vision. Hence, to attain fully in this manner the purpose of a microscope, a very strong light, concentrated by a suitable mirror or lens, must be directed upon the object. When the light of the sun is used in such a case, the complete apparatus is called the *Solar microscope*, and serves well to display the structure of many minute objects. When artificial light is used, as that of a lamp, the apparatus is called the *lucernal microscope* or *Magic Lantern*.

822. The *Solar microscope* was highly valued until the improvements in the construction of lenses were made, by which the dispersion of light, or the rainbow fringe, was prevented, and until the electric light could be substituted for that of the sun. With the table microscope, only one person at a time can see the wonder; but with the solar microscope, or with the photo-electric microscope, a whole company may enjoy the spectacle simultaneously.

The well-known *Magic Lantern* consists of a powerful lens, with objects, highly illumined by artificial light, placed so near it that their images are formed far off, and are therefore proportionally larger. The objects are generally paintings made on thin plates of glass with transparent colours; and the plates are formed to slide in a groove behind the lens, and are hence called slides. The distance of the lens from the object may be varied, and thus a corresponding approach to or receding from the screen is allowed, which will vary the magnitude of the visible picture on the wall.

A thin mist or smoke at night will sometimes reflect the images of a magic lantern so as to make them distinctly visible; and this is one method of summoning up spectres by a concealed lantern upon an artificially-produced smoke. Another method is by the use of *dissolving views.* In this case two lanterns are employed, and in the midst of the scene, bright and clear, displayed by the one, appears more or less hazy or spectral as desired, the figure of the other illuminated by a less bright light. An improved form of magic lantern has been constructed by Mr. Woodbury, under the name of *Sciopticon.*[*] There are two lenses, and these can be so adjusted as to cover a surface, ten feet square, with a perfect illumination by the use of a Kerosene lamp. It can also be used for dissolving views and other purposes.

“ *The* EYE *itself is, in fact, but a small camera obscura.*”

823. The account above given of the camera obscura describes closely also that most interesting object, the living eye itself—the great inlet of man's knowledge, and the window through which is perceived much of what passes in the mind within! We shall describe the eye and its actions, keeping present the idea of the camera obscura; and we shall find that the nature and uses of the various parts of the eye are declared by merely naming them. This paragraph should be perused while the reader can observe his own eye reflected in a mirror, or the eyes of friends near him.

The *human eye*, then, is almost a perfect sphere of the size of a large walnut, having for its outer wall, C, a very tough membrane, called, from its hardness, the *sclerotic coat*, which is, in common language, the *white* of the eye; in the front of this there is a round opening or window, E B, named, because of its horny texture, the *cornea.* The chamber is lined with a finer membrane or web, the *choroid* (having relation to colour), which, to insure the internal darkness of the place, is covered with a black paint, the *pigmentum nigrum.* This lining is bordered at the edge of the round window by what may be called a folded drapery, the *ciliary processes*, hidden from without by being behind the curious contractile window-curtain, the *iris* (so named from its rainbow variety of colour in different persons), through the central opening of which, called the *pupil*, the light enters. Immediately behind the pupil is suspended, by attachments among the ciliary processes, the *crystalline lens*, D, a double convex, perfectly transparent body of considerable hardness, which so refracts the light passing through it from external objects, as to form perfect images of these objects, in the way already described, on the back wall of the eye, G, over which the innumerable filaments of the optic nerve, called the *retina*, are spread as a sensitive lining. The eye is maintained in its globular form by a watery liquid, which distends its external coverings, and which, in the space before the lens, or *the anterior chamber of the eye*, being perfectly clear, is called the *aqueous humour*, and in the remainder or larger *posterior chamber*, being inclosed in a pellucid spongy structure, so as to acquire somewhat of the appearance of melted glass, is called the *vitreous humour.*

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[*] From σκια, a shade, and οπτικος, optical.

824. The annexed figure represents a vertical section of an eye of an average size, so as to show the edges of the coats, &c. C is the outer or *sclerotic* coat (fig. 198); A is the transparent cornea, somewhat resembling a watch-glass: it is more bulging than the sclerotic, or forms a portion of a smaller sphere than the general eye-ball, so that while it may be truly called a *bow-window*, it, with the convex surface of its contained water, forms a powerful lens for acting to converge the pencils of entering light. At B, and similarly all round the edge of the cornea, is attached the window-curtain or *iris*, shown here edgeways, immersed in the aqueous humour, and extending inwards from above and below towards its central opening or *pupil*, through which the rays of light are passing to the lens. The iris has in its structure two sets of fibres, the circular and the radiating, which cross and act in opposition to each other, keeping the membrane flat and tense; when the circular fibres

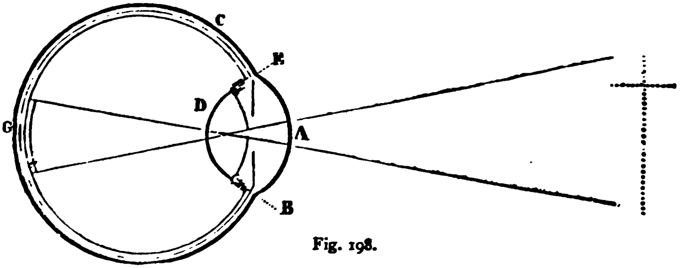

Fig. 198.

contract, the pupil is lessened, when the radiating contract, it is enlarged. These changes happen according to the intensity of light and the state of sensibility of the retina, as may at any time be proved by closing the eyelids for a moment to make the pupil dilate, and then opening them towards a strong light, to make it contract. Behind the pupil is seen the *lens*, D, with its circumference attached to the *ciliary processes*, E : it is more convex behind than before. The disease of the eye called *cataract* (from a Greek word implying *obstruction*), exists when the lens becomes opaque, and the cure is to extract the lens entirely, or to depress it to the bottom of the eye, and then to substitute for it externally a powerful artificial lens or spectacle-glass. The three lines marking here the external wall or boundary of the eye stand for its three coats, as they have been called, the strong *sclerotic*, and the double lining of the *choroid* and *retina*. The figure of a cross is represented upon the back part of the retina as formed by the light entering from the cross without (which cross has to appear here small and near, although representing one large and distant). The image of the cross is inverted, for the same reason as it is in the camera obscura : but we learn that the perception of an object may be equally distinct in whatever position the image may fall upon the retina. It has been explained above, that a lens cannot well form imagery of great extent except on a concave surface,—and the retina is such a surface. The *anterior* and *posterior chambers* of the eye are the compartments which are before and behind the crystalline lens, D.

The nature of the eye as a camera obscura may be studied by taking the eye of a recently-killed bullock, and after carefully cutting away the back part of the two outer coats, going with it to a dark place and directing the pupil towards any brightly illuminated objects. There may, then, be seen through the semi-transparent retina, left as a screen at the back of the eye, a minute but perfect picture of all the objects in front—a picture, therefore, formed on the back of the little apartment or camera obscura, by the agency of the convex cornea and lens in front, just as occurs in our artificial camera. The picture is inverted, for reasons explained above. The sclerotic coat of the eye of a rabbit is comparatively thin. When a rabbit's eye is held before a candle in a dark room, with the cornea in front, a beautiful inverted image of the candle is seen.

Phenomena of Vision.

825. *Upright Vision from Inverted Images.*—Because the images formed on the retina are always inverted as respects the true position of the objects producing them—just as happens in a simple camera obscura,—persons have wondered that things should appear upright, or in their true situations. The explanation is simple. It is known that a man in bed with his cheek on the pillow judges as correctly of the position of the objects around him, as any other person—never deeming them to be inclined or crooked, because their images on his retina are inclined in relation to the natural perpendicular when the head is erect. Boys who at play bend themselves down to look backwards from between their knees, although a little puzzled at first, because the usual position of the images on the retina is reversed, soon see as correctly in that way as in any other. It appears, therefore, that while the mind studies the form, colour, etc., of external objects in their images as pictured on the retina, it judges of their position, not by the accidental position of the image on the retina, or by receiving it as a whole, but by the *direction* in which the light comes from the object and its parts towards the eye—no more deeming an object to be placed low because its image is low in the eye, than a man in a room into which a sunbeam enters by a hole in the window-shutter, deems the sun low because its image is on the floor. In a preceding article (p. 576) it has been demonstrated, under the head of Refraction, that a coin placed in a basin of water is not seen in its true position, but raised above it, the eye judging the object to be in the direction of the line by which the light arrives. An arrow placed with its point upwards in front of the eye, is seen with the point uppermost in accordance with the direction in which the rays of light reach the retina or sensitive membrane. If the arrow were placed horizontally in front of the eye, with its point to the right, there would be no difficulty in comprehending that as the rays of light pass from the point on the right they must impinge on the retina to the left, and it could be seen only in its true position on the right, *i.e.*, in the direction taken by the rays. A similar observation applies to an arrow placed perpendicularly or in any other position before the eye. The eye does not see the image, but sees by means of the image.

826. Other illustrations present themselves. Thus a candle carried past a key-hole throws its light on the opposite wall, but the luminous spot moves in a direction the opposite of that in which the candle is carried; and a child must be very young who has not learned to judge at once of the true motion of the candle by the contrary apparent motion of the image. A boatman, who, being accustomed to his oar, can direct its point against any object with great precision, has long ceased to deem it strange that when he desires to move the point of an oar in some one direction, his hand must move in the contrary direction. Now the seeing of things upright by images which are inverted, is a fact of the same nature.

827. It is only in the centre of the retina that vision is perfectly distinct. This is felt at once by looking at a printed page, and observing that only the two or three letters to which the axis of the eye is directed, are clearly seen; and, consequently, although the whole page is depicted on the retina at once, the eye, in reading, has to direct its centre successively to every part. Then it may be remarked, in viewing the diagram of the eye, that the centre of the retina is more distant from the lens than any other part of it, and, consequently, that when the centre is at the true focal distance required for the formation of a perfect image, no other point of the retina can be so at the same time.

On examining a dead eye, the point of distinct vision is distinguishable from the retina around, by being rather more transparent. It might have been expected that this point would be where the optic nerve enters the eye; but, in fact, the optic nerve enters considerably nearer to the nose than the point of distinct vision; and the part is altogether blind or insensible. Had the two optic nerves therefore entered at points of the retina *corresponding* (in the sense explained above), there would have been an invisible spot on every object, opposite to the insensible points; but as the case really stands, the part of any object from which the light passes to the insensible or blind part of one eye, cannot be opposite to the insensible part of the other. The existence of the blind spot (or *punctum cæcum*, to give its Latin name), where the nerve of the eye enters, is discoverable by placing in a row on a table some small objects, as coins or wafers, about three inches apart, and one eye being closed, by looking with the other at a middle object of the row: the object next to that, on the outside, will then be invisible, although those still farther off will remain in sight. Another mode of proof is to shut one eye while looking with the other at the nails of the two thumbs held together at arm's length before the face; on then moving the outside thumb sideways away from the other, while the eye continues directed to the other, the moved one, when at the distance of about three inches, will disappear, but will come into view again when still farther removed.

Since the distance of perfect images behind a lens varies, there cannot be perfect sight unless where a perfect image is formed on the retina; and according to the various distances of the objects in front, that is to say, according as the pencils of light which fall upon it have more or less of divergence in them, it follows, that the eye, in being able, as it is, to see distinctly objects at different distances (the shortest is about five inches), possesses a power of altering the relation of its parts to accommodate itself to the circumstances. This is called the adjustment of the eye to distance. Among the eyes of the myriads of mankind, however, it happens that all do not originally possess such powers exactly in the requisite degree, and that many lose them from a natural decay as life advances.

828. Persons are called *short-sighted*, whose eyes, from too great convexity of the corona or lens, have so strong a bending or converging power that the rays of light entering them are brought to a focus before reaching the retina —at *a*, fig. 199, for instance, instead of at *b*; so that the rays when spreading again beyond the focus, where they cross one another, produce on the retina that sort of indistinct image which is seen in the camera obscura, of which the screen is too distant from the lens. This defect of sight obliges the individual, when using the naked eye, to hold objects very near to it, that the consequent greater divergence of the rays may be proportioned to the unusual refracting power of the eye;—or the person may find a remedy in placing concave lenses between the object and the eyes: these lenses lessen the convergence of the rays from objects at the usual distance, and cause the perfect images in the eye to be formed farther from the lens, and thereby on the retina itself. Without *concave spectacles*—as the lenses are called when fixed together in a frame,—persons with the defect now under consideration cannot see objects distinctly from a distance exceeding ten or twelve feet. This defect often diminishes with years, so that the person who in youth needed strong spectacles, in old age sees well without them.

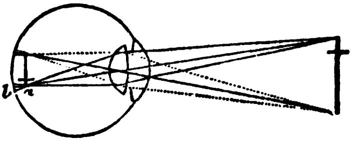

Fig. 199.

There is the opposite defect of deficient convergent power in the eye, dependent on a too great flatness of the cornea or lens, and which is much more common than the last-mentioned defect. The great majority of persons after middle age begin to experience this in some degree. In such cases the rays of light are not collected quite into a focus when they reach the retina; they would meet only at *b*, for instance (fig. 200), instead of, as they should do, at *c*, and hence the image is indistinct, in the same manner as in the camera obscura, when the screen is held too near to the lens. Persons suffering from this defect cannot, when using the naked eye, see distinctly any object very near to it, because the deficient converging power of the eye cannot conquer the great divergence of rays coming from a near point; hence, they will remove objects under examination, as a book or newspaper, to a considerable distance, even to that of arm's length, so as to receive from them only rays nearly parallel. These persons, in contradistinction to the last described, are called *long-sighted* persons. This defect is remedied by the common convex spectacles, which do part of the converging work, so to speak, before the light enters the eye, leaving undone only that which the weakly converging eye can easily accomplish. As this defect, like the last, is met with in all degrees, spectacles must be chosen accordingly.

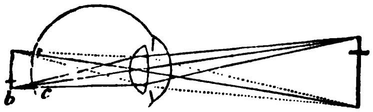

Fig. 200.

829. Up to a recent time it was believed that the change in the state of the eyes, which comes on about middle age, obliging most persons to use spectacles, was simply a weakening of the converging power of the eyes; but the writer found, in his own case, that the defect arose chiefly from double images of the objects being formed in each eye, one image being strong, as usual, and the other being more faint, overlapping the first, and jutting beyond it towards the right hand. For a time he deemed this a peculiarity in his own case, but accident leading him to examine further, he found that a great majority of the persons using spectacles had the same defect. As the age of these was greater, the double vision was more marked, and the displacement to the right of the fainter image was greater. Old people found that while a broad object had only a shadowy projecting edge on the right side, tall narrow objects, like a flagstaff, a long chimney, or a slender steeple, appeared two, standing distinctly apart The parties had not been clearly aware of the fact, but it was easily proved thus :—Two lines of equal strength or breadth are drawn on paper directly crossing each other. If such cross be then held before the eyes, one line being vertical and the other horizontal, the horizontal line appears thicker and darker than the other. The explanation is, that the displacement to one side (generally the right side) of the faint image of the cross leaves the horizontal lines of both still coinciding, and therefore dark, while the vertical lines are separated, and therefore appear broader and less dark. To a person having this defect, a printed page seems to have double letters, and if the lateral displacement amounts to only half the breadth of a common letter, the faint downward lines of the one set appear between the stronger lines of the other, and darken all ; but if the displacement be greater, the shadowy lines may coincide with the stronger, and so are, in great part, concealed, except at the very end of the lines. The same clearing effect may be produced by holding the page farther from the eyes. Happily the common spectacle lenses remedy, to a considerable extent, this defect, as well as the feeble convergence.*

An eye much accustomed to examine near and minute objects may lose something of its pliancy, and become defective when tried at distant things, as that of the miniature painter, the engraver, &c. On the other hand, the old seaman's eye, which has so often and uninterruptedly been directed to the distant horizon, straining to catch the view of an expected sail, or of land, has a power of judging of distant things which surprises, while in regard to small, near things, it experiences deficiency.

830. A man who tries to see with the eyes under water has very indistinct vision, because the difference of density between water and the eye not being so great as between air and the eye, the bending or refraction of light entering from the water is not so great as to produce perfect images on the retina. Aid would be given in such a case by using very convex spectacles. It is to meet the necessity of the case that the lens of a fish's eye is extremely convex, or almost spherical. The white round ball found in the eye-socket of a boiled fish is the crystalline lens of the fish coagulated or hardened, as white of egg is hardened, during the boiling.

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* The adjustment of the lens of the eye differs for horizontal and for vertical lines ; the distance of distinct vision being greater for the former than for the latter.

Pouillet, in speaking of the eye, describes it as a perfectly achromatic instrument. This has been denied by some eminent physicists, but it is quite certain that in a healthy state, no object appears to be surrounded with any halo of colour, and, practically speaking, the eye is perfectly achromatic for all the purposes of correct vision.

Any impression of light made upon the retina lasts for about the sixth part of a second. According to some, it is only the eighth or eleventh part of a second. Hence, when the burning end of a stick is made to sweep rapidly across the view, its path appears to the eye to be a long continuous line of light; and if it be made to revolve in a circle six times in a second, as when moved by the hand, or fixed to a turning wheel, that circle will appear to the eye to be a complete ring of fire. A small polished ball of steel on the end of an elastic wire, of which the other end is fixed in a block of wood, when caused to vibrate, similarly forms a line or a curve of light. A harp-string while vibrating as it sounds, appears like a flat transparent riband. Lightning or other meteor darting across the sky, although in fact but a single luminous point, is generally thought of as a long line of light: the term forked lightning has reference to this illusion. The same remark applies in a degree to a sky-rocket in its rapid ascent. Two or more colours painted separately on the rim of a wheel which is made to turn rapidly, appear to a spectator to be these colours really mixed:—it has been explained already how patches of all the colours of the rainbow, when mixed in this way on a turning wheel, form white light. If on one side of a card a little bird be painted, and on a corresponding part of the other side a cage be shown, on then making the card turn rapidly by twisting between the fingers and thumbs threads fixed to its opposite edges, the bird and cage will be seen at once, and the bird will appear to be within the cage.

831. A large class of optical toys depend for their explanation on the sensible persistence of impressions on the *retina*, the general popular expression "an optical illusion," being commonly employed to explain the whole class.

The *Zoetrope*, or *wheel of life* (invented in 1860), is one of the most common and interesting of these. It consists of a cardboard cylinder mounted on a vertical axis, so that it can be whirled round rapidly. A number of slits (twelve or more) are cut at equal distances round the cylinder, and at half its depth. On the inside of the cylinder, is placed a strip of paper having the object to be viewed, depicted in as many different attitudes as there are holes in the disc, the successive attitudes representing those taken up in the performance of any action, such as rising from a chair, making a somersault, or throwing up and catching a ball. If, when the cylinder is rotated, we look through the slits at the figures, the persistence of the impressions on the retina fuses them all into a living motion with surprising resemblance to actuality.

The *Anorthoscope* is a somewhat similar contrivance. It consists of two discs, one whirling in front of the other and in an opposite direction. In the front one is a series of radial slits, in the back one a set of distorted figures. When they are set in motion, the figures, viewed through the slits, start into regular proportions.

The *Phenakistoscope*, as it has been called, consists of a disc having a set of figures painted on an inner circle, and a set of radial slits on the outer concentric circle. On whirling, and looking through the slits at the reflection of the figures in a mirror, they instantly appear to be all alive.

832. A certain intensity of light is necessary for distinct vision, but the degree varies much according to the previous state of the organ. A person passing from the bright day into a shaded room, may for a time fancy himself in almost total darkness, but by persons sitting in the room, and become accustomed to the feeble light, every object is clearly seen. The dawn of morning after the darkness of night appears much brighter than an equal degree of light in the evening. When, as the night falls, lamps or candles are first introduced, their moderate glare is often for a time offensive to the eye ; and a similar feeling, but still stronger, when in the morning, bed-room window shutters or close-drawn curtains are suddenly opened. After the repose of night, the sensibility of the eye, when first opened, is often such that a window with its frame, or a dressing-table with a glass, or any other object, first seen in a strong light, will so impress the retina that in closing the eyes the images will appear and remain for some time. To a prisoner after long confinement in a dark dungeon, the full light of day is almost insupportable. A dungeon, which to unaccustomed eyes is utterly dark, still to its long-held inmate may seem feebly illumined. The darkness of a total eclipse after bright sunshine, appears deeper than it really is. The long polar night, which lasts for months, ceases to appear very dark to the inhabitants of the country.

If an eye be directed for a time to a black wafer laid on a sheet of white paper, and be then turned to another part of the sheet, a portion of the paper at that other part, of the size of the wafer, will appear brilliantly illuminated ; because the ordinary degree of light from it appears intense to the part of the retina lately receiving almost none. An eye directed long and intensely to any minute object—as when a sailor watches a speck seen in the distant horizon, supposed to be a ship, or when a sportsman on a brown heath, keeps his eye fixed on a bird nearly of the colour of the heath, or when an astronomer gazes long at a little star—has the sensibility of its centre at last weakened, and ceases to perceive the object ; but if the axis of the eye be then turned a little to one side of the object, so that an image may be formed only *near* the centre, the object may be again perceived, and the centre, in the meantime enjoying repose, will recover its power.

833. But the most striking fact connected with the sensibility of the retina is, that if part of it be strongly exercised for a time, by looking at some bright-coloured object, on the eye being then turned away or altogether shut, an impression or image will remain of the same form as the object lately contemplated, but of a different colour, deemed the opposite or complementary colour of the other. Thus if an eye be directed for a time to a red wafer laid on white paper, and be then shut or turned to another part of the paper, a beautifully-bright green wafer will be seen ; and *vice versâ*, a green wafer will produce a red spectral image, violet will produce a greenish yellow, and yellow a violet, and a cluster of wafers will produce a similar cluster of opposite colours. Then if the hand be held over the closed eyelids to prevent almost entirely the access of light to them, the spectral image of a bright object, lately viewed, will appear luminous surrounded by a dark ground, and when the hand is again removed the contrary will be true. Again, if the eye be considerably fatigued by looking at the setting sun, or even at a window with a bright sky beyond it, or at any very bright object, on then shutting it, the lately contemplated forms will be perceived, first of one vivid colour, and then of another, until perhaps all the primary colours have passed in review. These extraordinary facts prove that the sensations of light and colour, although excitable by light, are also producible without it. This truth gave occasion to Darwin's theory, that the sensation of any particular colour, as red, for instance, is dependent upon a certain state of contraction of minute fibres in the retina,—and that the fibres, when fatigued in that condition, seek relief when at liberty, by throwing themselves into an opposite state,—as a man whose back is fatigued by bending forward, relieves himself not by merely standing erect, but by bending the spine backwards.

834. *Complementary colours.*—The term complementary is derived from the Latin *compleo*, to fill up. If the seven colours of the spectrum are painted in their due proportions on a disc, the complementary colours correspond to directly opposite parts of the circle. They may be thus set down in order,—

Red.	Greenish blue.
Orange.	Sky-blue.
Yellow.	Indigo.
Violet.	Greenish yellow.

Each colour with its opposite, produces by blending, white light, a fact demonstrated by experiments on polarized light (see p. 690), as well as by the rapid revolution of a card-disc painted with the two colours. Helmholtz has proved that yellow and blue are complementary (Tyndall). This might seem inconsistent with the well-known fact that blue and yellow pigments undoubtedly produce green, but, as Tyndall observes, the mixture of pigments is totally different from the mixture of lights. Certain solids, liquids, and even mixtures of gases, split white light into its complementary colours and are what are called dichroic, *i. e.*, of two colours. The red colouring matter of blood dissolved in an alkali is green by reflected and red by transmitted light. Other red liquids have a similar property. Gold-leaf reflects a deep red colour, but the transmitted light is greenish coloured. The atmosphere in a large mass reflects a splendid blue (sky-blue), but the light which it transmits, as seen in the rising or setting sun, is yellow or orange. In all these cases of dichroism, the light is actually sifted; that which passes through is the balance or complement of the rays which do not penetrate, but undergo reflection. The two sets of rays constitute white light.

A shadow produced by coloured light, is seen with the complementary colour of that which produces it. Thus the orange-coloured light of the rising or setting sun produces on a white ground a beautiful sky-blue shadow. This, no doubt, proceeds from the reflected light of the atmosphere when the transmitted light is cut off. The light of the moon is a pale greenish blue. The shadows which it produces on a white surface, in the presence of artificial light, are red or reddish coloured.

> "*The mind judges of external objects by the relative size, brightness and colour of the minute but perfect images or pictures of them formed at the back of the eye on the expansion of nerve called the retina; and the art of the painter is successful in proportion as it produces on a larger scale such a picture, which, when afterwards held before the eye to reproduce itself in miniature upon the retina, may excite nearly the same impression as the original object.*"

835. We now understand how an exact miniature resemblance of the objects before us is produced upon the retina of the eye, by the light from them refracted in passing through the different parts of the eye; but after all, this is only a picture, and the inquiry remains —which many persons would suppose so simple as to be trivial, but which is in reality very curious and important—how are we thereby enabled to judge of the magnitudes, distances, and other particulars respecting the things examined. Here it will be found, to the surprise of persons first entering upon the study, that we learn the meaning of a scene or of pictorial signs only gradually, as we do of any other system of signs, and that a person whose eyes, although perfect, had been kept covered from infancy up to maturity, would no more "see" and understand any scene on which he first opened his eyes, and so had a perfect picture of it on his retina, than a child understands or can read a printed page, when he first looks into a book. Highly interesting information has been obtained on this subject, by observing the facts where an obstruction from birth has, by a surgical operation, been suddenly removed in persons arrived at maturity.

If a man were placed from infancy in an apartment fitted up as a camera obscura, and had no means of becoming acquainted with the external world, but by watching the images appearing from time to time upon the screen, he could learn scarcely anything of objects around him; but if after a time he were allowed to walk out, and to examine by the touch and by measurement, the different objects whose images he had been in the habit of viewing, and to ascertain what size, shape, and distance of an object corresponded with a certain magnitude, form, position, and brightness of image, the transient imagery might at last be to him a tolerably clear indication of the real particulars; making him in imagination present to the objects, nearly as if he went out and examined them with his hands

Thus, in a degree, the mind may be considered as stationed in or near the little camera obscura of the eye, from whence it cannot itself escape to examine external nature, but must learn the meaning of the images formed on the retina, through the services of the bodily members, and the other organs of sense, examining the realities. The judging of things by sight, then, is merely the interpreting one set of signs, as judging by sounds or language is interpreting another, and judging by hieroglyphics or any written characters is interpreting a third. The common visual signs on the retina, however, are among signs the most easily learned or understood, from having certain fixed relations in form, magnitude, and position to the things signified: while words, hieroglyphics, and written characters are quite arbitrary, and have no such relations.

Pictorial Representation and Perspective.

836. BODIES, as visible objects, differ and are distinguished among themselves chiefly by their comparative dimensions, that is, their form and magnitude, or shape and size; and to ascertain these and the relative distances and positions, are the great objects which, by means of the eyes, the mind seeks to accomplish. It effects its ends by considering collectively,

1st. *The space and place* occupied by objects in the field of view, measured by what is called the *visual angle.*

2nd. *The intensity of light, shade, and colour.*

3rd. *The divergence of the rays of light entering the eye.*

4th. *The convergence of the axes of the eyes viewing an object.*

We shall treat of these particulars separately in the order now stated.

1st. *The space and place occupied in the field of view, measured by the visual angle.*

837. The term *field of view* is used to designate that open or visible space before the eyes, in which objects are seen; and it may mean either the smaller field visible in one position of the person's head, or that which is commanded on directing them all round. This is called the *sphere* of vision. If a man, as at *e* (fig. 201), were surrounded by a globe or sphere of glass, as *a*, through which his eye, placed at the centre, might view the several objects around occupying certain situations and certain proportions of the circumference; and if the globe had any equal divisions or degrees marked upon it all around like the lines marking, on a library globe, the degrees of longitude and latitude, he would be able at once to say exactly what portion of his sphere or field of view was shadowed or occupied by any single object, as the cross here shown at *i*, and thus to describe very intelligibly, its relative magnitude and situation as then appearing to him. For example, he might say, on looking at a tree in the garden through a common window (which is a portion of the field of view really divided by the cross-bars), whether he saw the whole tree through one pane or through several, and through which pane or panes he saw it. It may be remarked farther, that whether the supposed sphere of glass were large or small, *viz.*, were as indicated at *a*, or *b*, or *c*, the part of its surface apparently occupied by any object either beyond it or within it, would bear the same proportion

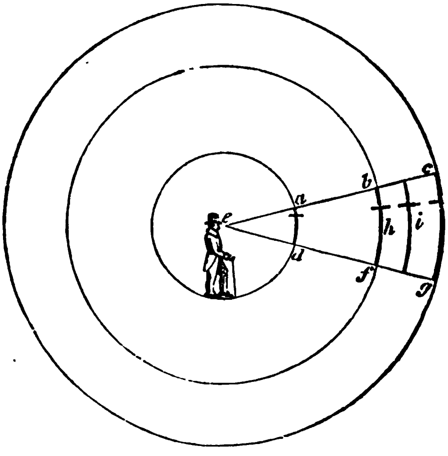


Fig. 201.

to the whole surface; if *a d* were a tenth of the small circle or globe, *c g* would be a tenth of a larger. Now as it has been found convenient to consider a circle (and every circle) as divisible into 360 equal parts, to be called degrees (which are smaller therefore in a small circle than in a large circle, although in each having the same relation to the whole), the ready mode of comparing the apparent magnitude of objects is to say how many of these degrees of the field of view, in length or breadth, each object occupies; and this is what is meant by the apparent size of an object. Then, because the most convenient way of measuring a portion of a circle, of which the whole is not seen, is to measure by a fit instrument the angle or corner formed at its centre by lines drawn from the extremities of the portion to the centre, as in fig. 201, the angle at *e*, formed by the lines *c e* and *g e*, the object is said either to occupy a certain number of degrees of the circumference of the circle, or to subtend an angle of the same number of degrees at its centre, and this angle is called the *visual angle.*

838. It is important to advert here to the difference between the length of line which measures the height or breadth of an object, and the amount of surface or space occupied by it in the field of view, the latter being always as the square of the former (see Art. 26). A single pane of glass, one foot high and one foot broad, forms a small window, but a window two feet high and broad has four such panes, and a window of ten feet borders has one hundred such. The full moon in the sky has breadth, or visual angle of nearly half a degree of the celestial vault; a moon twice as broad would have four times the surface. In the diagram of the field of view (fig. 201) the figures of the cross span about thirty degrees of the circles, and the cross itself is made curved to coincide with the circle; but for small angles the portions of the circle included between the bounding lines, being so short, are regarded as straight lines without leading to error. The adjoining figure illustrates several of the matters here referred to.

The visual angle, in regard to any object, being that included between the two lines or rays, as *a u* and *d i* (fig. 202), which pass from

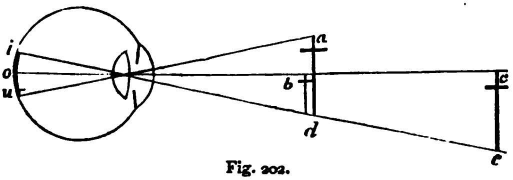


Fig. 202.

the extreme points of the object, *a d*, for instance, to form the extremes of the corresponding image on the retina at *i u*; it is evident, as shown also in Art. 820, that the same angle is formed by the rays on each side of the lens, and that the image on the retina is less than the external object in exact proportion as its distance from the centre of the lens is less than that of the object. It follows also, therefore, that the small cross, *b d*, produces the same-sized image on the retina as the cross, *c e*, which is twice as large, but twice as distant; and that an image only half as large as that from the cross, *a d*, when near, is produced by a similar cross, *c e*, when twice as far removed. The visual angle then becomes an exact indication of the size of the object when the distance is known, or of the distance when the size is known.

Many familiar facts receive their explanation from the law of the visual angle or apparent size being less always in proportion as the distance of an object is greater.

839. A man (or the cross here substituted for simplicity) at *d* (fig. 203), standing near the outside of a window, *b c* (here supposed to be seen edgeways), may, to the eye of a spectator within the window at *h*, subtend the same visual angle, or appear as tall as the window, the light from the man's head passing through the top of the window, and that from his feet passing through the bottom; but if the man then move away from the window, the eye of the spectator will be able to see his whole body through a smaller and a smaller extent of the window, as his distance increases; through half its height, or *a c* (fig. 203), when he is twice as distant, or at *f*, and through the third, or *o c*, when he shall be three times as distant, or at *g*, and so forth, for any other distance; so that soon a small figure of a man cut in paper, if applied upon the glass, would exactly cover the part of it through which the light from his body entered to the spectator's eye, and would then, by completely hiding him from view, be an exact measure of his *apparent* size; at last a fly passing over the pane might equally hide him, and the fly then would subtend a larger visual angle than he does, that is, would be forming on the retina a larger image than the man. Thus it may happen, that a person sitting near a window, and intent upon some subject of study or of conversation, may for an instant mistake a fly on the glass for a man at a distance; or, on the contrary, a man for a fly.

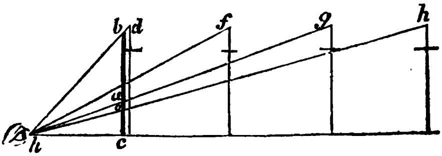


Fig. 203.

In accordance with the principle now explained, a telescope has been constructed in which the field of view is divided by fine cross wires, or otherwise, so that the person using it can say at once how much of its field any object occupies. When ships are in chase, it is common by such an instrument, which will detect a change of visual angle, or apparent size, to view the fleeing or pursuing ship; and if the apparent size be observed to increase, the conclusion follows that the ships are nearing each other; if, on the contrary, the size diminishes, the chased ship is escaping.

840. By computation according to this rule, whenever the real size of a distant object is known, the distance is ascertainable, and, *vice versâ*, when the distance is known the size is determinable; for it is evident that if a body, as a ship, known to be 100 feet tall, occupy or subtend in the field of vision the 360th part of a whole circle, or one degree, the whole circle must be in circumference 360 times 100 feet, or 36,000; and the diameter of any circle being $\frac{1}{3}$, or more nearly $\frac{7}{22}$ of its circumference, while in the case supposed the distance of the ship is the half-diameter, we learn that distance Again, if we know the distance of a ship or other object to be a mile, and if we then find the visual angle subtended by the object to be the 1000th part of a circle, we know its true size to be the 1000th part of a circle, of which the half-diameter or radius is one mile. It is by applying this rule in a manner to be afterwards explained, that the size of the heavenly bodies is determined.

Few persons are aware of how rapidly the apparent magnitude of an object diminishes on its being removed farther from the eye. A removal of 100 feet renders the image formed on the retina by any object 100 times smaller than when the distance is one foot. Now, in the unaided human eye, the power of seeing minute objects has a limit, namely, when the object subtends in the field of view an angle of space of less than half a minute. There are many kinds of minute animals thus hidden from common unaided vision, owing to their small size, but which the microscope clearly shows, and proves them by their activities, to see one another as larger animals do. It has been common to believe that mere distance prevents the eyes from seeing minute things somewhat as a fog or other such obstacle does, and not because of the small size of the images then formed on the retina.

841. We now perceive that if the rays of light coming to the eye through a plate of glass set in a picture-frame, from objects seen beyond it, could leave marks in the glass at the points where they pass, and marks capable of giving out the same kind of light as the objects give, there would be formed *upon* the glass such a representation or picture of the objects viewed *through* it, that when held before the eye, it would produce on the retina an image or images the same in almost all respects as the objects themselves. From the different points of the glass, light would shoot to the eye of the same kinds and in the very same directions as that originally coming from the objects. Now the art of painting seeks so to dispose lights, shades, and colours on some plane surface, as to produce the sort of representation of objects here contemplated, while the picture-frame stands in lieu of the window-frame, or border of any opening through which the true scene is supposed to be viewed. It is admirable how perfectly this art now accomplishes its ends; and although there are still differences between the effect upon the eye of a picture and of the realities—which differences we shall consider presently, and how they may be combated so as to render the illusion almost perfect—it is not one of them, as might be supposed from the small extent of the canvas, or plane of the picture, that the images made on the retina are smaller than when produced by the objects themselves. Few people, before studying this subject, are aware that in good pictures, the different figures are in size made such that, at the distance from the eye at which the picture is meant to be viewed, they produce on the retina, the very same size of image as would be produced by the realities seen under the aspect represented in the picture. To become sensible of this, a person may look through a window-pane, having the eye fixed, at the distance of a foot from it, and may trace with a sharp point or pencil upon the glass (previously coated with gum) the outline of the scene beyond, perhaps a street or garden, and he will find that the outline of a man seen there at the distance of thirty paces, may be made perfectly to coincide with the person, so that, if opaque, it would just hide the person, will be scarcely half an inch tall, while the figure of a man a few hundred paces off will be so small that the eyes, nose, and other features could not be distinguished, even if they could be drawn.

842. It is remarkable that, although no fact in nature is more familiarly known to all, than that the apparent size of bodies is constantly changing to a person moving about among them, as explained in the preceding paragraphs, few have stated to themselves that philosophical truth. They soon learn, even as children, to make the necessary allowances, and move about safely among the things around them, judging correctly enough of sizes and positions of things. Then, as a person who reads the description of an elephant, does not deem the animal larger or smaller because of the size of the types used in the printing, or of the accompanying engraved representation; and as a man, in a picture-gallery, viewing miniatures and larger portraits, does not conceive of the originals according to the size of the representations; and as a man viewing a correctly-executed picture of a Grecian temple, never dreams, unless his attention be specially directed to the fact, that, upon the canvas, the distant pillars of the rows are drawn much shorter than the near ones,—the mind in all such cases merely using the *signs* to help it to conceive of the *things* according to previous knowledge, or to other principles of judging; so in any common case of examining by the eyes, the mind takes small account of the *apparent* size of objects, but passes instantly from the types to the realities, already in general more or less known. Few persons, for instance, reflect on the fact, that when two friends shake hands, each appears to the mere eye of the other much taller than when either has gone some paces away; or that one chair of a set, at the end of a room, appears to a person sitting at the other, only half as large as a chair in the middle of the room. But such facts may be immediately proved by looking through a tube or a ring at the same object when placed at different distances from the eye. Of a chair standing near, only a small part will be visible through the tube, while of a distant chair the whole and others around may be seen. At a few miles' distance a fleet of a hundred ships, or a mountain, may be seen through a finger-ring as the picture-frame. There are occasions, however, where previous knowledge and common collateral helps to the recognition of objects being wanting, the observer's attention is strongly aroused to the fact of the diminutive appearance produced by their distance; for instance, when a man, after a long sea-voyage, first approaches a land, of which the features are new to him, as when a European first arrives on an Indian coast, he can scarcely believe that the little specks which he sees scattered along the shore are spacious dwellings, or that what seem to him only luxuriant herbs or bushes, are magnificent palm-trees.

843. For the same reason that a distant body to the naked eye, appears diminutive, namely, the smallness of the visual angle subtended by it, so does a distant motion to the eye appear slow. A railway train dashing past a spectator at rest may startle, nay, appal him by its speed; but if viewed, at the same time, by another from the side of a distant hill, it seems to be gliding gently along. A ship driven before a tempest seems to a sailor on board almost to fly through the white foam which surrounds her; but if then seen by a spectator on shore, she is scarcely perceived to change her place. A balloon high in the air, borne along on the wings of the wind, at the rate of seventy or eighty miles an hour, may still for a considerable time leave a spectator on earth doubtful whether it be in motion at all, or in what direction it moves. The moon in her orbit wheels round the earth at the rate of hundreds of miles an hour, yet, owing to her distance from it, her motion is not visible to the naked eye of the inhabitants of the earth, except by comparing her positions at considerable intervals of time. In respect to bodies still more distant than the moon, the truth at present under consideration is still more striking.

Having now explained how the apparent transverse measure or breadth of bodies and of space, in other words, the visual angle subtended by them, is affected by their distance from the eye, we proceed to show how it is affected also by their position.

Because light moves in straight lines, no part of an opaque body can be seen, between which and the eye there is not straight open space. A globe before the eye, however turned, preserves the same appearance in the field of view, and its outline traced upon a plate of glass held across between it and the eye, is, like its direct shadow upon a wall, always a circle; but an egg, which if held in one position produces a circular outline or image, when held in another, produces an image which is oval. A wheel when viewed sideways appears a perfect circle, when viewed edgeways it appears a broad straight band or line, and in any intermediate position it appears oval. The *apparent* form of a body, then, may give only partial information as to its shape, to be taken with the experience of seeing it in other aspects. If a man had never seen an egg but endways he could not have known that it was not a sphere.

844. If any long straight object, as a wooden beam, be placed with one of its ends directly to the eye, that end only can be seen, and according to the case, may appear a square or circle of the diameter of the beam; if it then be placed with its side directly to the eye, its whole length will be seen; and if placed in any intermediate position, it will appear more or less shortened; in all cases, its outline on the retina being similar to that of its shadow on a wall behind the person. A man has advanced on the point of a spear turned directly to his eye without seeing it, or on the end of a bar of iron carried on the shoulder of a porter in the street. A common telescope held with its end to the eye appears a perfect circle, if then inclined a little, it seems to jut out on one side, and as the inclination is increased, it juts out more and more, until it displays its whole length. A great ship of war, of which the stern is towards a near spectator, might appear to him a round wooden building with ordinary windows; but as it turns, or as the spectator moves to one side, it gradually reveals the long batteries of cannon. A straight row of a thousand similar objects, as of trees, pillars, or soldiers in rank, may appear to a person at the extremity, as only one object of the kind, the nearest individual completely hiding all the others; but if viewed from the side and at a certain distance, the individuals may be counted. The appearances now treated of, exemplify what is called *foreshortening*, and are to be noted wherever surfaces or lines are not placed so as directly to face the spectator.

845. One of the commonest cases of foreshortening is when the eye looks more or less obliquely along an extended plane surface, on the ground, for instance, or on the face of the sea, by estimating aright the foreshortening of which, judgment is formed of the distance or situation of the objects placed thereon. And it will be readily perceived that in all such cases the more distant portions of the surface, are progressively more foreshortened than the nearer. Thus, a man standing at *a* (fig. 204), on a plain, as *a b*, with his eye at *c*, if looking down before him, looks on a portion of the surface, *a d*, almost directly, or with little foreshortening, and an extent, as *a d*, equal to the height of the eye, will subtend in his eye an angle of 45°, or half a right angle, *viz.*, the angle, *a c d*, which is half of the whole angular space subtended from his feet to the horizon, however distant; the next equal portion of the plane, *viz.*, *d f*, will subtend a much smaller angle, *viz.*, *d c f*, the next, *viz.*, *f c g*, an angle smaller still, and so on, as he carries his view more and more forward, the surface becoming more and more oblique to his visual ray, until at last the light rather skims along the level than rises. This explains why a person having a side view of a row of separate objects, as of men in line, trees, or pillars, can look through or between the nearest of them, but towards the extremity sees them as if standing in close contact, or as if forming a continued surface. The same remark explains why distinct masses of cloud, scattered uniformly over the sky, with wide

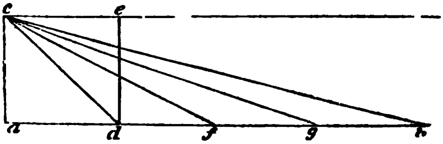


Fig. 204.

intervals of clear blue between them, may appear to a spectator, anywhere on the ground, to form, towards the distant horizon, a dense unbroken bed.

846. If a man standing on a hill look down upon a field or plain which is known to him, and if he see some objects near its side, and some near its middle, and some near its distant border, he judges fairly by the angles how far they are from him and from one another. Similarly, when viewing the ocean from a lofty peak, and seeing ships scattered over its face, he judges tolerably of their distance, for he can see only a certain extent of ocean which becomes to him as a known field. The man stationed at the flagstaff on the High Knowl of the island of St. Helena, looks down upon a circular field of the Atlantic, a hundred miles broad, and can tell the distance of any sail in sight to within a few miles. Although the ground plan of an extensive landscape may not be so level as the face of the ocean, there is still an approximation, which considerably assists a spectator's judgment of dimensions.

Painters are careful not only to foreshorten, according to the proportions explained above, all the objects seen obliquely which they portray, but they avail themselves of this principle to produce very striking effects. For instance, the accomplished Martin, the painter of *Belshazzar's Feast*, in many of his beautiful designs, by judicious foreshortening, exhibited miles in extent of gorgeous architecture and of armed men, on a very small extent of canvas: he made a single magnificent pillar or accoutred warrior in the foreground, serve as the type which first warmed the mind with admiration, and then sent the conception along retiring lines of beautiful perspective, where every tip or edge renewed the first impression.

A man lying on a high table or bed, with his feet towards the spectator, is foreshortened into a roundish heap, of which the soles of the feet hide the greater part. This is the description of the painting which was called the "Miraculous Entombment," in viewing which an unreflecting spectator, while moving sideways, with the expectation of seeing more of the body, still saw only the soles of the feet, and could suppose the body to be turning round so as to keep the feet towards him. For nearly the same reason, the eyes of a common full-face portrait, may seem to follow a spectator while going to different parts of the room,—for by moving to a side of the picture he cannot see the side of the eye-balls. A rifleman portrayed as if taking aim directly in front of the picture, appears to every spectator to be pointing at him specially.

847. As the painter, availing himself of a knowledge of the principles now explained, by which the eye usually judges of size and distance, may produce on his canvas charming illusions, so may the tasteful proprietor of ornamental gardens and pleasure-grounds, by working his solid levels into artificial undulation of hill and dale, and clothing these with tree and edifice of magnitudes to correspond—make the eye of a spectator contemplate supposed extensive plains, lofty mountains, spacious lakes, and distant pagodas—all within the narrow space of a few acres; so, by another set of means, producing on the eyes of observers nearly the same impressions as Claude, Poussin, or Turner have given by their noble pictures.

When the representation of any object or mass of objects is foreshortened, because one part has to appear farther from the eye than another, that part is made in a proportion smaller than equal parts nearer. For example, in a straight row of similar houses, pillars, or trees (see fig. 205), those nearest to the eye will, on a pane held before the eye to receive their light, occupy the larger space, and there will be a gradual diminution from the largest to the least, so that lines drawn upon the glass along the tops and bottoms of the images would tend to a point, called, for a reason to be explained below, the *vanishing point.* Thus a person looking from a window along a straight street, must, in order to see the chimneys of the nearest house, look through the top of the window, and to see the street door must look through the bottom; but the most distant house, both top and bottom, is to be seen through a small extent of the glass level with the height of the eye. This remarkable tapering of foreshortened objects may of course be strikingly observed on looking at any correctly-made drawing or engraving intended to represent a retiring row of similar objects;—such drawing being, in truth, an attempt to realize by art, on the surface of a sheet of paper, the appearance of the objects as seen through a window or aperture of the size of the paper; or, as would be seen on the glass of a window, if rays of light could leave marks in passing.

848. *Perspective.*—The art which gives rules for tracing objects on a plane surface, as they would appear to an eye looking at them through that surface if transparent, with their various degrees, first, of apparent diminution, on account of distance, and, secondly, of foreshortening, on account of the obliquity of view, is called, from the Latin word, *perspicio,* signifying *to look through,* the *art of perspective.* It regards chiefly the two particulars now mentioned; and, notwithstanding the terror with which, in the imagination of many young painters, the study of it is clothed, by reason of the mathematical difficulties with which it has usually been surrounded, it is in itself very simple. A student can scarcely make a more instructive experiment than to take a framed drawing or engraving of a view from some window, and having set it up near the window, to place by its side an empty frame of the same size. By then comparing the reality, viewed as a picture, through the empty frame, with the true picture fixed in the other, their perfect accordance becomes very striking in regard to the sizes, positions, and shadings of the parts, all illustrating the rules of perspective. Although, without a knowledge of these rules, a quick eye soon enables its possessor to sketch from nature with much truth; and although the two instruments, the *camera obscura*, already described, and *camera lucida*, to be described in a future page, give almost mathematical accuracy to drawings made with their help, without requiring other skill in the draughtsman than to trace and make permanent, with ink or pencil, the lines of light which he sees on the paper; still the subject is so interesting to all who attempt to sketch, and, indeed, to all who wish to look intelligently either at nature or at works of art, that none who have the opportunity of studying it, should neglect the study.

Supposing straight rows of similar objects, as of the stone blocks, or pillars, or houses represented in fig. 205, from *a* or *b* to S, to run directly south, and to be viewed by a person stationed at a window over the point, C, between and near the end of the rows forming the street, *f*, *d*, then, because, as already explained, objects to the eye

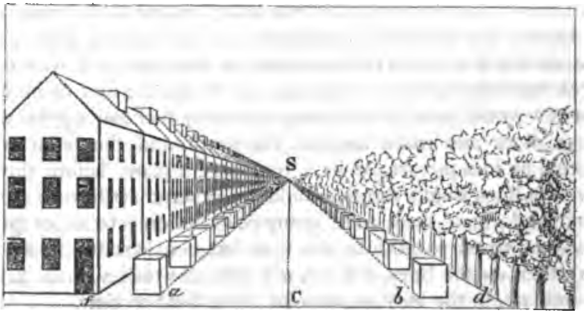


Fig. 205.

appear smaller in proportion to their increased distance from it, the second block, if twice as far off as the first, would appear only half as large; the third, if three times as far, would be only one-third as large, and so on to any extent, and for any other proportions; and if the thousandth or any other block, owing to its distance, subtended to the eye an angle less than the sixtieth of a degree of space in the field of view, it would be altogether invisible, even if nothing intervened between it and the eye. For the same reason that the size of the blocks would appear smaller, the distance between corresponding or opposite blocks in the two rows, would appear less and less, until the rows would seem to meet. Then, where the rows and the blocks cease to be visible from the minuteness of the parts and distances, and from the fact of the nearer ones concealing those farther off, they are said to have reached their *vanishing point.* When a student of perspective has learned what regards the vanishing *point* in relation to sizes, distances, and positions of objects, he has learned half of his art. The above cut is to be considered as the representation of a street, running directly south to S, sketched from a window opposite to its end looking along its centre.

849. It is important here to remark, that in any case of a straight line, or a row of objects thus vanishing from sight, as here the line or row, *a* S, in whatever direction it lies from its beginning, whether east, west, north, or south, in that direction, exactly from the eye of the observer, will its remote or vanishing extremity disappear. In this sketch the row *a* S. is supposed to run directly south; and, although the eye, to see the beginning or near end of it, would have to look towards the left or east end, and to see the first block of the other row would have to look west, still every successive pillar would appear more and more towards the south, and the point in the heavens, or in a picture, or in a transparent plane before the eye, where the lines would vanish, would be exactly south from the eye. Then, similarly, if there were many rows of objects, as of pillars, houses, or trees, parallel to the first, but considerably apart from each other, as the lines, *a* S, *b* S, *d* S, still all would vanish, or seem to terminate, in the very same point of the field of view.

850. The reason of this important fact may be thus explained:—Let us suppose a line drawn directly south from the eye to the point S, between the parallel lines of pillars, houses, and trees, *a* S, *b* S, *d* S, also pointing directly south, and let us suppose the two rows of pillars to be one hundred feet apart, then evidently for the same reason as the space between the top and bottom of the pillars, that is to say, their height, becomes apparently less and less as their distance from the eye increases, so will the space between each pillar and its opposite in the other row, or between it and the point corresponding to it in the visual ray along which the eye looks, become *apparently* less, and therefore the lines of pillars, really and everywhere 100 feet apart from each other, and 50 feet from the visual ray, will, at a certain distance from the eye (*viz.*, where a space of 50 or 100 feet is apparently reduced to a point), appear to join, and the three lines will appear to meet in that point, beyond which none of them can be visible, and which is therefore the vanishing point of all. It aids the conception of this truth to suppose a planet visible in the exact point of the heavens, S, at the moment of observation; then, if the three parallel lines were continued on to the planet, and were visible all the way, they would arrive there with the interval between them just as when they left the earth; but as a planet, although thousands of miles in diameter, owing to its distance from the earth, appears on earth only as a point, much more would two lines only 100 feet apart be there undistinguishable in place by human sight. What is true of a space of 100 feet between parallel lines, is equally true of a space of a mile or of thousands of miles. As a general rule, therefore, it holds, that all lines really parallel among themselves, when represented in perspective, tend towards, and if continued, end in, the same vanishing point—which point is the situation where the line terminates, along which the eye looks when directed parallel to any one of the real lines. This is true not only of lines lying in the same level or horizontal plane, such as might be formed across a lake, but also of lines placed one above another, as those running along the tops and bottoms of the pillars here, or along the walls, roofs, and windows of the houses, or along the roots and summits of the trees, and indeed of all lines in whatever situation, provided they are parallel to one another, and therefore to the visual ray. This truth holds equally with respect to short lines which do not reach the vanishing point, or centre of the picture, as with respect to those which do. When it is ascertained therefore that a line or boundary of any natural or artificial object has a certain inclination to the axis of the picture, or to what we have described as the principal visual ray, then also is it known that all the parallels to that line have their vanishing point in the same spot of the field of view, and a line supposed to be drawn from the eye into space, or really drawn from the eye to the picture in that direction, marks upon the picture or its plane extended, the true vanishing point of such lines.

851. It will now be understood why, in a long arched tunnel, or a cathedral, with many longitudinal lines on its floor, walls, roof, &c., all such lines, seen by an eye looking along from one end, appear to converge to a point at the other, like the radii of a spider's web; and why, similarly, in the representation of the interior of an ordinary room (fig. 206), here sketched as viewed from one end, all the lines of the corners, tops and bottoms of windows, floor, stripes on a carpet, edges of tables, &c., being in reality parallel to one another, tend to the same vanishing point at V. The appearance of the lines in the floor of this room may recal that of the furrows in a ploughed field as seen from one end, when they appear like the ribs of a fan spread out towards the spectator.

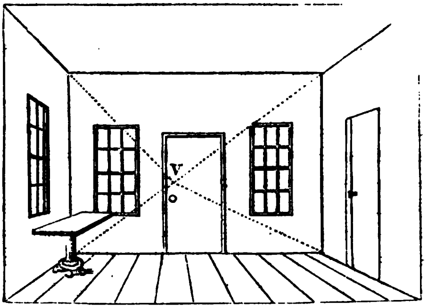


Fig. 206.

852. By far the most important vanishing point in common scenes is the middle of the line of the horizon, and in a picture properly placed it is at the exact height of the eye of the spectator. It is marked S in figs. 205 and 207, and V in fig. 206. Because in houses, the roofs, foundations, floors, windows, tables, and other furniture, &c., are nearly all horizontal, the vanishing points of their principal lines and surfaces must be somewhere in the horizon, and for most of them near the middle of the picture. In holding up a picture-frame, through which to view a scene suitable for a picture, it is found most generally befitting to cause the line of the horizon to cross the frame at about one-third from the bottom of it: this fact becomes the reason of the rule in painting, so to place the horizontal line of the picture. In beginning a picture, this line is usually the first line drawn on the canvas, as marking the place of the vanishing points of all level lines and surfaces. And the eye of the spectator is supposed to be placed before the middle of it, and generally about as far from the picture as the picture itself is long, such being the extent of view which the eye at one time most conveniently commands.

Understanding now that the apparent or perspective direction of all lines in a scene is towards their vanishing points, and the rule having been given for determining these points in a drawing, it is now to be inquired how much of a line drawn to any vanishing point belongs to the known magnitude of the object which it touches; in other words, how much an object is in perspective foreshortened in consequence of its distance and obliquity of position in regard to the eye.

853. If we suppose A S P (fig. 207) to represent a plate of glass standing edgeways, on which a picture might be painted, and that towards the point, S, in it an eye is looking horizontally from the point, D; evidently then, a line from P continued in the direction of B and beyond, until vanishing from sight, would have as its perspective image or representation on the glass the line from P to S; S being then the *point of sight* in the picture, and the pictorial vanishing point of the line, P B, however far extended. Now, to divide the *representative* line, P S, so as to correspond with any given portions of the *original* line, P B, &c., it would be necessary only to draw other lines from the place of the eye, D, to the line, P B, in the situations desired, and these lines would cut the perspective line, S P, in the proportions required. For instance, the portion of true line, *a b*, would be represented by that portion of the image line, S P, included between the two lines, *a* D, and *b* D, and so of any other portions.

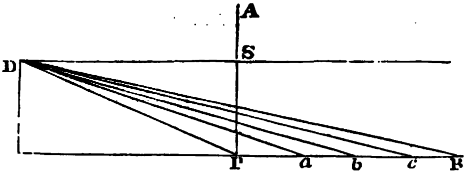


Fig. 207.

854. There are figures drawn on mathematical scales by which such problems as the above can be at once approximatively solved; and it would be possible by trigonometrical calculation to solve them exactly in all cases; but the most generally convenient mode in practice is to sketch on the intended drawing (as that of which the boundaries are given in the adjoining figure, 208) the kind of measure required, by setting off from the point of sight, S, a distance on the horizontal line, as at D, equal to the distance of the eye from the picture, and then by oblique lines drawn from D to the base line, P R, to cut the perpendicular line, P S, in the situations desired.

This is done in the last figure, which differs from the present chiefly in having the *point* of distance, D, marked *before* its point of sight, instead of here, *laterally*. And the line, P S, being always cut by the oblique line from D in proportion to the length of base-line concerned between P and the extremity of the oblique line, a horizontal line drawn through any point in the line from D, cuts in due proportions the other lines which have their vanishing points in the horizontal line, at S, for instance, *a* S, P S, &c. Thus, to draw in perspective, on the surface above represented and prepared, a chess-board or board of squares, it is necessary to set off half the breadth of the board on the base-line to the right and left of P, *viz.*, at *b* and *a*, and then to draw to the point of sight, as a vanishing point, the lines, *a* S and *b* S, part of which lines will therefore represent the sides of the board, and then to draw the diagonal, D *b*, which for the reasons above stated will cut the lines, P S and *a* S, in proportion to the length of base-line to the right of their extremities; *a e f b*, therefore, is a square seen in perspective, and any number of smaller included squares are made by drawing lines from the vanishing points to equal divisions on the base, and making cross horizontal lines where the diagonal cuts these.

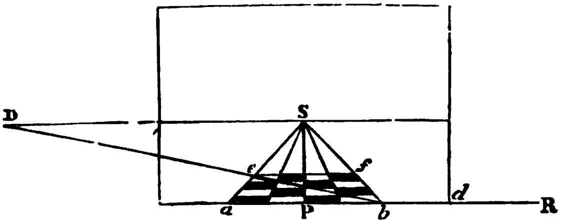


Fig. 208.

855. Much of the delight which the art of painting is calculated to afford is lost to the world, because persons in general are not taught how to look at a picture. Unless a spectator place himself where he can see the objects in true perspective, so that he may fancy himself looking at the realities through a window or opening, everything must appear to him false and distorted. The eye should be opposite to the *point of sight* of the picture, and therefore on a level with the line of the *horizon*, and it should be at the required distance from the picture, which is generally at least as great as the length of the picture. It needs not to be said that the fault of the artist cannot be remedied by any position of the spectator. It is very common, for instance, to see miniature resemblances of architectural structures so foreshortened and tapered that the eye, to see them in true perspective, would require to be within an inch of the paper. These at the usual distance from the eye of ten or twelve inches are seen as hideous distortions. The specimens in the few preceding pages necessarily exemplify in a degree this error, because the *point of distance* had to be marked where there was but a small page. The figures, therefore, by any person studying the subject in detail, should be drawn on a scale so much larger as to allow the eye really to view them at the distance supposed.

856. A means of judging of the dimensions of bodies by the visual angle, and which depends neither on the absolute size of the image, nor on the foreshortening of the ground plane on which the body stands, is, to use known objects in view as measures for others near them which are unknown.

If a person of our acquaintance be standing at some distance from us near another person who is a stranger, we know how tall the stranger is by taking the acquaintance as a measure.

In pictorial representations of objects previously unknown, as to young people must at first be the Egyptian pyramids, the bodies of the whale, the elephant, or the camel, human beings may be represented around them to serve as measures for the less-known object. The Colossus of Rhodes seen from afar might to a stranger have appeared but an ordinary statue of a man, but the exact magnitude would have been known as soon as a ship of known dimensions were seen sailing into port between his gigantic limbs.

When an unpractised eye is first directed from a distance to a great ship, it will on many accounts dwell upon the object with wonder and admiration ; but it may not judge truly of the enormous magnitude until it sees another vessel of known size near to it, or can perceive the sailors climbing on the rigging, and appearing there, by comparison, as little birds appear among the branches of a lofty tree.

By having a measure of this kind presented to us, the magnitude and elevation of great edifices are rendered more obvious. The magnificent pile of St. Paul's, in London, becomes still more striking to persons passing by when they discover visitors looking from the balconies near the summit-cross. These appear so minute among the surrounding huge masses that for a while a spectator is disposed to doubt whether they can be full-grown men.

Many persons cannot distinguish between the little pilot balloon (sometimes despatched before a great one to show the direction of the wind) and the great balloon itself, until under the last they perceive the aëronauts as little black objects in the basket.

Strangers visiting Switzerland, on first entering a great valley there, are often deceived as to its extent. Being familiar generally with more lowly hills and shorter valleys at home, which, however, from being near to the eyes, form bulky images, and having at first no other measure of comparison, they almost universally underrate the Alpine dimensions:—they will wonder, for instance, in the valley of Chamouni, that they should be travelling swiftly for hours without seeming to approach the end.

The author, in sailing past the Canary Islands, had a view of the far-famed Peak of Teneriffe. It had been in sight during the afternoon of the preceding day, at a distance of more than 100 miles, disappointing general expectation by appearing then only as an ordinary island rising out of the ocean; but next morning, when the ship had arrived within a shorter distance, and while another ship of the fleet, of seventy-four guns, holding her course six miles nearer to the land, served as a measure, it stood displayed as the most stupendous object which had ever been seen by most of those on board. The great ship in question appeared but as a speck rising from the sea, when compared with the huge prominence beyond it towering sublimely far above the clouds. Teneriffe alone of high mountains rises very directly out of the bosom of the ocean to an elevation of 13,000 feet, and, as an object of contemplation, therefore, is more impressive than even the still loftier summits of Chimborazo or the Himalayas, which rise from elevated plains, and in the midst of other heights only a little less elevated than themselves.

It is because objects which are nearly on a level with us, as contrasted with such as either rise much above or fall much below, are usually surrounded by other known objects which serve as measures of comparison, that we judge so much more correctly of the size and distance of things near our level than of others.

A man walking like ourselves on the sea-shore or other level, may be recognized at a considerable distance; and probably it may not occur to us, that he appears much smaller on account of the distance; but if the same man be seen afterwards at an equal distance above us, collecting the sea-fowl's eggs on the face of a cliff, or if afterwards, when we have ourselves reached a height, we see him gathering shells on the beach, he appears no bigger than a crow; yet in both cases he is where the same bulk forms the same magnitude of image on the retina.

Even on a horizontal plain, if the general surface be bare and uniform, single distant objects appear very diminutive. This is true, for instance, of a man seen apart from his caravan, while journeying across a flat desert; but a man viewed at an equal distance, in the midst of a cultivated landscape or among any known objects, appears of his natural size. The same is true of a single boat or ship seen out on the high sea, as contrasted with like objects viewed in a crowded harbour.

857. We may now understand why the sun and moon, at rising or setting, appear to us much larger than when they have attained meridian height—although, if we examine them by any precise measure of the visual angle, as by looking at them through a known ring or tube, we find that there is no difference. The sun and moon as they appear from this earth are nearly of the same size, each occupying in the field of view about the half of a degree, or as much as is occupied by a circle of a foot in diameter when held 125 feet from the eye—which circle therefore at that distance, and at any time, would just hide either of them. When a man first sees the rising moon apparently filling up the end of a street, which he knows to be 100 feet wide, he naturally believes that the moon then subtends a greater angle than usual, but the reflection may occur to him, that he is using as a measure, a street known indeed to be 100 feet wide, but of which the part concerned, owing to its distance, occupies in his eye a very small space. The width of the street near to where he stands may occupy sixty degrees of his field of view, and he might there see from between the houses broad constellations instead of the moon only, but the width of the street far off may not occupy, in the field of view, but a small part of one degree, so that the moon, which always occupies half a degree, will there appear comparatively large. The kind of illusion now spoken of is yet more remarkable when the moon is seen rising or setting beyond still larger known objects,—for instance, beyond a distant hill or island, which appears all within the luminous circle. Any person who, from Greenwich Park, has observed the sun setting beyond London, with St. Paul's Cathedral included within its circumference, will recollect a very interesting example of this kind. Another example is afforded by the case of a balloon at a great elevation seen crossing the disc of the sun or moon, and then appearing, however large in reality, as an absolute speck within the vast luminous area.

It may be remarked here, that the visual estimate formed of the great size of the sun and moon when seen on the horizon, is not an illusion, as was at one time popularly supposed, but an approximation to truth, only prodigiously short of the reality. When a distant tree, or a house, or a hill is seen, apparently within the circumference of one of these orbs, it is really as true that the orb is larger than the tree, or house, or hill, as that a distant hill, similarly surrounding by its outline a nearer hill, would be larger than that; but the celestial body is so much larger than anything interposed on earth, that even if the whole of Britain could be lifted away from the earth, and suspended near the moon, as a map in the sky, it would hide from a spectator on earth but a small part of the disc beyond.

Having now shown that the visual angle or apparent size becomes a measure of the distance of any object, only when the true size is known, or of the true size only when the distance is known, we proceed to examine other means which the eye possesses for estimating distances.

2nd. *Intensity of light, shade, and colour.*

858. It has already been explained that light, like every other influence, radiating from a centre, becomes rapidly weaker as the distance from the centre increases, being, for instance, only one-fourth part as intense at double distance, and in a corresponding proportion for other distances; while it is still farther weakened by the obstacle of any transparent medium through which it passes. Now persons soon become sufficiently familiar with these truths to judge from them, with considerable accuracy, of the comparative distances of objects.

The Gothic pile of an ancient cathedral may break upon the view in some situation where nearer edifices, and perhaps some minor imitations of its beauties, already fill the eye with their strong lights, but the misty or less distinct outlines of the venerable pile warn the approaching stranger of its true magnitude, and prepare him for the enjoyment which a nearer inspection of its grandeur and perfection is to afford.

A small yacht or pleasure boat may be built according to the same model or with the same comparative dimensions as a first-rate ship of war, and may be in view from the shore at the same time, only so much nearer than the ship, that both shall form images of the same magnitude on the retina of a spectator. In such a case, an unpractised eye might have difficulty to discriminate, but to an old seaman the bright lights of the little vessel, contrasted with the softer or more misty appearance of the larger, would declare the truth at once. A haziness occurring in the atmosphere between the little vessel and the eye, might considerably favour the illusion.

In a fleet of ships, if the sun's direct rays fall upon some here and there through openings among the clouds, while the others remain in shade, the former in appearance start towards the spectator. In like manner, the mountains of an unknown coast, if the sunshine falls upon them, appear comparatively near, but if clouds again intervene, they seem to recede, mocking the awakened hope of the approaching mariner.

A conflagration at night, however distant, appears to spectators generally as if very near, and inexperienced persons often run towards it with the hope of soon arriving, who find after miles travelled that they have made but a small part of the way.

A person ignorant of astronomy deems the heavenly bodies vastly nearer to the earth than they are, merely because of their being so bright or luminous. The evening star, for instance, seen in a clear sky over some distant hill-top, appears as if a dweller on the hill might almost reach it—for the most intense artificial light which could be placed on the height would be dim to a distant spectator in comparison with the beauteous star; yet to a dweller on the hill it appears just as distant as to one on a remote plain.

The concave of the starry heavens appears flattened above, or as if its zenith were nearer to the earth than its sides or horizon, because the light from above having to pass through only the depth or thickness of the atmosphere is little obstructed, while of that which comes towards any place horizontally through hundreds of miles of dense vapour-loaded air, only a smaller part arrives.

The sun and moon appear larger at rising and setting than when midway in the sky, partly, as already explained, because they can then be easily compared with other large objects, of which the size is known, but partly, also, because of the much less light arriving from them in the former situation, while their apparent diameters remain nearly the same.

859. A fog or mist is said to magnify objects seen through it. The fact is, that, because it diminishes the intensity of the light from them, it makes them appear more distant without lessening the visual angles subtended by them; and because an object at two miles, subtending the same angle as an object at one mile, is twice as broad, the conclusion is drawn that the dim object is large. Thus a person in a fog may believe that he is approaching a great tree, fifty yards distant, when the next step throws him into a low bush which had deceived him. Two friends meeting in a fog, often mistake one another for persons of greater stature then theirs. There are, for similar reasons, frequent misjudgings in late twilight and early dawn. The purpose of a thin gauze screen interposed between the spectators in a theatre and some person or object on the stage meant to appear distant, is intelligible on the same principle; a boy near, so screened, is meant to appear a man at a distance. The art of the painter uses sombre colours when his object is to produce in his picture the effect of distance. On the alarming occasion of a very dense fog coming on at sea, where the ships of a fleet are near to each other, without wind, and where there is considerable swell or rolling of the sea, much damage is apprehended.

860. The celebrated *Spectre of the Brocken*, among the Hartz Mountains, is a good illustration of the present subject. On a certain ridge, just at sunrise, a gigantic figure of a man had often been observed walking, and extraordinary stories were related of him. About the year 1800, a French philosopher and a friend went to watch the apparition; but for many mornings they paraded on an opposite ridge in vain. At last, however, the monster was seen, but he was not alone; he had a companion, and, singularly, he and his companion aped all the motions and attitudes of the two observers; in fact, the spectres were merely shadows of the observers, formed by the horizontal rays of the rising sun falling on a morning fog which hovered over the valley between the ridges; and because the near shadows were very faint, the figures were deemed distant, as of gigantic men walking on the opposite ridge. A comparatively small figure seen near, but supposed distant, appears of gigantic dimensions.

861. While the different intensities of light coming from bodies considered as wholes, furnish an indication of their different distances from the observer, the comparative intensities from their sides unequally exposed to the sources of light, and therefore illumined or reflecting light to the eye, in different degrees, indicates the forms and attitudes of the bodies. In observing, for instance, a white house exposed to the sun, it is seen that the side receiving the rays directly is highly illumined or bright, while the other sides are much less so, and are said to be in the shade—a shade which is more or less deep in proportion as there are few or many sources of reflected light bearing on it. The different faces or walls of such a house are, to the sense of the observer, as strongly distinguished from each other, by the mere difference of shade, as if they were of different colours, or as if they were examined by the touch, or by walking round them. If the object examined were a ball instead of a square house, there would still be the great differences of shade in the parts not receiving direct rays, but instead of forming abrupt contrasts at corners like the walls of a house, they would appear to melt into each other, marking the beautiful round contour of the object. The consideration of all such cases forms the subject of light and shade, or *chiaroscuro*, so interesting to the painter.

Had there not been in nature the provision of light and shade, the sense of sight would have been of comparatively little use, and a mass of things in the light, if of the same colour, would have been as little distinguishable from one another by a person looking directly at them, as a mass of things are, in their common shadow formed on a wall. It is this provision, therefore, which enables us, independently of colour, to distinguish the profiles or outlines of different bodies placed near to one another, and to distinguish in the same body the protuberant, or hollow, or other form of the surfaces which are towards the observer. But for this, it would have been impossible to distinguish, for instance, between a white wall when bare and when having various white objects placed upon or before it; and it would have been impossible to distinguish clearly between the rounded figures of a flat circle, a sphere, and a cone, similarly coloured, and with axes pointing to the eye; but in reality, by differences of shade, the white objects are distinguished from the wall, and in the three geometrical figures mentioned, the uniformly bright surface of the circle, the soft rounded shadowing of the sphere, and the shade coming to a point on the cone, at once declare the true forms. But for the shadowed parts, the façade or front of a white palace of curious architecture would have been an unmeaning sheet of light; the lights and shadows, however, produced by the juttings and recesses, mark the variety of surface very completely; the round pillar is distinguished from the square, and every pediment, capital, and architectural ornament stands out pleasingly conspicuous. But for light and shade, again, the "human face divine" would have been a uniform unmeaning breadth of flesh, instead of having the differences produced by different exposures to the light, which cause every prominence and depression, and every momentary change, to be so truly indicated to the eye that it becomes full of meaning or expression. How well mere light and shade serve to convey what the eye has to learn of a scene or object, may be perceived by examining any of the admirable engravings which now abound, and which, although made up entirely of degrees of shade, or of black and white, are scarcely inferior in expression to finished paintings.

862. The student of painting soon learns that the hard tracings called outlines, by which he first sketches subjects, do not exist in nature, and have to be again effaced in his finished work ; for they mark the place where lights and shades happen to meet. Much may be conveyed to the mind, however, by a mere outline, and particularly if lines of different breadth or thickness are used to indicate the situation of the fainter and deeper shadows.

The subject of chiaroscuro is not so simple as, from the fact of the sun being the great source of light, might at first be supposed; for although this be true, still every body which reflects the sun's light becomes a new source to the bodies around it, and the shading of a picture must have reference to all such sources, and to the different colours of the body itself, and of the neighbouring bodies.

In looking at an extended landscape, it is seen that the near objects, or those in the foreground, are comparatively bright, with their shadows strongly marked, and their peculiar colours everywhere easily distinguishable—as of flowers, fruit, foliage, &c., but of objects farther off and apparently diminished in size, the colours, with increasing distance, become dim, the lights and shadows melt into each other or are confused, and the illumination altogether becomes so faint that the eye at last may see only a certain extent of sombre mountain or plain—appearing bluish, partly owing to the reflected colour of the atmosphere (Art. 834), and partly because the quantity of light which can pierce the great extent of air, is insufficient to exhibit the detail. The ridge called the Blue Mountains in Australia, another of the same name in America, and many others elsewhere, are not really blue, for they possess all the diversity of scenery which the climates can give, but to the eyes which first discovered them, and viewed them from a distance, they all at first appeared blue, and they have retained the name.

In a good picture where, upon canvas stretched on a frame, the artist has disposed the lights, shades, and colours in the very situations and with the intensities which they would have had if coming from the real scene to the eyes, through a plate of glass filling up the frame, all that we have now been saying is strictly exemplified. In the foreground the objects are large and bright, but as they are supposed to become gradually more remote, the size and brightness correspondingly diminish, until at last there is only a dim mixture of bluish or greyish masses forming the boundary of horizon and sky.

863. A child, during what may be called the education of the sense of sight, has a strong perception of the vast differences of appearance which things assume according to their accidental distance from the eye, their position, and their exposure to light; for many of these differences, being at first calculated to deceive the young judgment, have from time to time been noted and recorded. Thus, a boy when he first discovers that a ship which at the near quay, with her sails outspread, concealed from him half the sky, is in an hour or two afterwards seen by him on the distant horizon as a dark speck hardly big enough to hide one star, has his attention strongly awakened, and he feels surprise; or, again, when he learns that the faint blue unchanging mass which he had always observed bounding in one direction the view from the home of his youth, is a distant mountain-side thickly inhabited, and covered with dwellings and gardens, where in succession the bright colours of the different seasons periodically glow—he is equally struck. But as soon as experience has enabled him to interpret readily and correctly the visual signs under every variety of circumstance, his attention passes so rapidly from them to the realities—just as it might pass from the paper and printing of a newspaper to the important intelligence communicated by them, that he very soon ceases to reflect that the sign, which in every case similarly suggests the object, is not also in every case like the object, and the same true and complete representation of the reality. The feeling that the sign must be like the thing suggested, becomes at last so strong, that even a difficult effort has to be made by a grown person again to attend to the mere *appearances*, in any scene of which the *realities* are known.

864. This attempt to analyse visual appearances, and to estimate truly their connection with realities, is called, as already stated, the study of *perspective*. When it regards the apparent reduction of size, and the foreshortening of bodies under various circumstances, it is called *linear perspective;* when it regards the fading of light and the modifying of colour, it is called *aërial perspective*. As the advanced art of painting depends so much upon the understanding of these two departments, the gradual progress which it has made in different countries is a measure of the degree in which the common prejudice that things *appear* exactly as they *are* has in them been overcome. Where this feeling exists, any untaught person conceives a good painting to be merely a miniature representation drawn according to a certain reduced scale—as of an inch to a yard—and in which all the dimensions of things should be measurable as simply as in the reality—while the colours as to vividness, &c., should perfectly agree with the originals. This statement is remarkably illustrated by the facts, that children in their rude attempts to paint, always aim at realizing such notion of the art, and that such has been the first stage of painting in every country. In Europe, owing to the labours of men of genius, art in painting may be said almost to rival nature, producing impressions on the retina as vivid as those from nature's own scenes, and scarcely distinguishable from them; but in other countries, as in China and India, among the native artists, the early stages of the art may still be studied. In many Chinese pictures, owing to the absence of perspective proportions, an extensive subject is only a collection of portraits of men and things drawn nearly on the same scale, and placed one above another, and where all the colours are as vividly shown as if the objects were only a few feet from the eye; the figures at the bottom, or foreground, are meant to represent the objects nearest to the spectator, while the figures higher up are supposed to be of more remote objects, all appearing as they might be seen in succession by a person who had the power of flying over the country. This kind of representation, although not natural if all viewed at once, may communicate more information than a single common painting, for it is equivalent to a succession of such. In Europe lately the principle has been usefully acted upon for certain purposes, as for representing on one long sheet, or on a succession of sheets connected in a suitable manner, the banks of a river or a line of road. The banks of the Rhine, particularly, have thus been admirably portrayed, so that the spectator directing his eye along the paper, feels almost as if carried in a balloon to view in detail the whole of the enchanting scenery. The bird's-eye view of the ancient city of Cologne, with all its famed architecture, and its noble modern bridge spanning the great river, is a portion of such representation.

3rd. *Divergence of the rays of light.*

865. This is the next circumstance to be mentioned by which the eye judges of distance. Supposing the line, E F, to mark the place and breadth of the pupil of the eye, the light entering from an object at *a*, which is near (it is here placed nearer than an object could be seen in reality), is very divergent, or is spreading with a large angle; from *b* the pencil of rays is less divergent, or opens with a smaller angle; from *c* it is less divergent still, and so on. Now the eye, to form an image on its retina, requires to exert a bending or converging power exactly proportioned to the divergence of the received rays; and the person has a sense of the effort made, which becomes a kind of measure of the distance of the object. This divergence of the rays entering the eye is an important circumstance in which the most perfect painting must still differ in its effect upon the eye from a natural scene,—for, first, in the natural scene, most of the objects are more distant than their representation can be; and, secondly, while in nature every object according to its distance is sending rays which reach the eye with corresponding divergence, the rays from a picture, which is a single plane surface, come from every part with nearly the same divergence, the eye must feel, therefore, a disappointment in not having to accommodate its power of bending to the different distances attempted to be portrayed on the canvas. It might be expected that this kind of disappointment would be more felt on looking at a common picture placed a few feet from the eye, than at the sort of picture called panorama, which is on a larger scale and proportionately more distant, but such is not always the case. The reason seems to be, that in the former the illusion is not assumed to be complete, for the fact of its being but a picture is not at all concealed, and the eye is therefore at once told to expect a difference of feeling; but in the panorama, the various circumstances are arranged to deceive the eye, if possible, entirely, and to make the spectator believe that the images on the retina are formed by light from the objects themselves. Then to the eye really deceived in all other particulars, the non-accordance with nature in this one, is quickly, and by some persons even painfully felt, so as, on their first entering the place, to occasion slight headache or giddiness. The illusion, and consequently the pleasure from

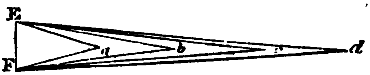


Fig. 209.

viewing pictures of distant objects, may be made more complete by the spectator using a single lens or a pair of spectacles, of focal distance nearly equal to the distance of the picture from the eye: because such lenses, as already explained, would render all the rays entering the eye nearly parallel, and therefore very nearly such as would reach it from objects at a considerable distance.

4th. *Convergence of the axes of the eyes.*

866. This is the last circumstance to be considered, by which a person, through the eyes, judges of the distance of objects. In consequence of there being two eyes, on the centres of whose retinas light from any object must fall in order that the person may have a clear vision of it, the axes of both eyes must be directed to the same point of the object. If it be very near, the optical axes will meet and cross each other very near to the face, exhibiting to bystanders the appearance called squinting, as when a man tries to look at the point of his nose; but for objects at greater and greater distances, the optical axes will become less and less oblique, until at length they are nearly parallel to each other. This state occurs, also, when persons are thinking of things not present, and, therefore, seen only by the mind's eye; and the countenance is then said to express contemplation or thoughtfulness. The following figure (fig. 210) serves to explain this part of the subject.

The two circles represent the eye-balls, looking along a middle line, A B C, directly in front. That line is fitly realized by a common yard measure, or a straight lath of wood, having three pins sticking in it at different distances, as A B and C. While the axes of the

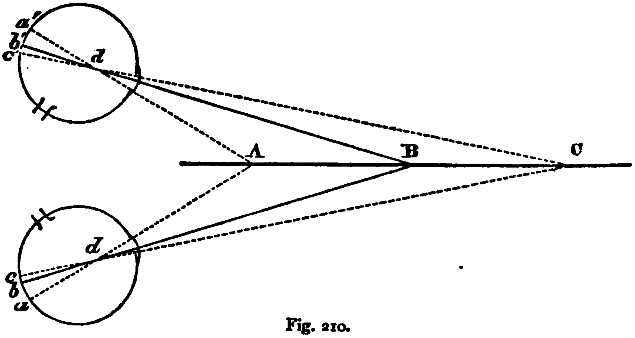


Fig. 210.

two eyes are directed to the object at A, they form at meeting a large or squinting angle, indicated by the letters *a* A *a′* : when they meet at B, the angle *b* B *b′* is smaller, or more acute : when they meet at C, the angle *c* C *c′* is smaller still ; and the different degrees of effort made to produce the necessary convergence, at the several points of which effort the person is as conscious as of that exerted to bring the hands together, to examine by touch an object in the dark, becomes a measure, to a certain degree, of the distances. There occur at the same time these other facts. While the eyes are directed to the pin at B, seeing it clearly and singly, by the rays indicated here by the strong lines, B *b* and B *b′*, they are receiving also from the more distant pin at C, rays of light indicated by the dotted lines, C *c* and C *c′* ; but the spots of the retina, *c* and *c′*, give the sensation of two images formed on less sensitive parts of the retina, and they are scarcely noticed. Then, further, the eyes are admitting light also from the pin at A, nearer to them than the object at B, which light reaches the spots of the retina, *a* and *a′*, on which two other indistinct images are formed. Thus, in any case of vision, the object on which the axes of the eyes meet is alone seen single and distinct, while any other objects at greater or less distances within the field of view, are seen double and indistinct. This is strikingly seen by looking along the rod and pins above described. It follows, of course, that the rod itself appears as two rods, except at the point supporting the object, to which the eyes are specially directed, and there the two appear to cross each other.

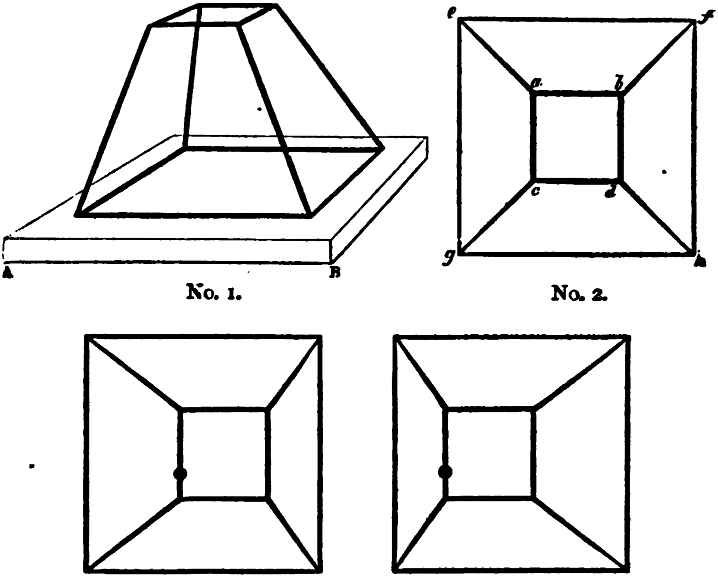
A still simpler experiment than that above described, is, to hold up a finger a few inches from the eyes, and while looking steadily at it, to attend to the more faint appearance of things farther off, or nearer, as a book, a picture, a candle. These all appear double. If two fingers be held up in a line, at different distances from the eyes, the one, looked at directly, is always single and clear, the other always double and indistinct. In reading printed or written characters, a person sees distinctly at one time only three or four letters, because these alone are sending light to a true focus in the centres of each retina ; but the other letters immediately around, although indistinct, do not appear double, because they are nearly at the same distance from the eyes as those well seen.

867. *The Stereoscope.*—In the last two paragraphs we have the means of explaining the singularly interesting invention of the late Professor Wheatstone, called by him the *Stereoscope* (στερεος, solid ;

σκοπεω, to see), another fruit of the same rare sagacity and exhaustless mechanical ingenuity which first devised and constructed for the world, the working Electric Telegraph.

As the eyes judge of the distance of larger objects around the person, by the degree of convergence of their axes, required to give perfect vision of these, so do they judge of the size and shape of single solid bodies, which may be regarded as collections of minute parts or points, joined together by the angles of convergence required to see clearly the relative distances of the different points.

A consideration of the following experiments brings the important particulars under review. In fig. 211, let No. 1 represent a solid outline formed in wire of a small pyramid, of which the top is wanting, placed on a block, A B. If a person look directly down upon this with one eye, it will have the appearance of No. 2, with perfectly equal sides, and equal angles all round, and with the small



No. 1. No. 2.

No. 4. No. 3.

Fig. 211.

square, *a b c d*, in the middle of the large one, *e f g h*. If it be then placed midway before the eyes, that is, opposite to the middle of the face, the right eye alone looking at it, will see the sloping surface of the right side more directly than that of the left side, and the appearance to that eye will be, as shown in No. 3, the small square, *a b c d*, appearing no longer in the middle of the larger, but nearer to the bottom line, *e g*, on the left side. If, then, the left eye alone be directed to the pyramid, it will appear as represented in No. 4, with the small square near the line, *f h*, on the right side. If a pane of glass, therefore, coated with gum, were placed between the eyes and the models, Nos. 3 and 4, and the view for each eye were traced on the glass, the tracing would be an exact counterpart of what is shown on this paper. This explains that two eyes cannot receive exactly similar images on each retina, at the same time, from the same solid body. By comparison, however, of the different images, a judgment is quickly made of the true form and position of the body. The experiment described may be made at once by setting up on edge between the two figures, Nos. 3 and 4, equally exposed to the light, a large card or a thin volume, so that when the eyes approach to within six or eight inches, each can see only the one drawing before it. The eyes then, after a little practice, will see, not the two drawings, differing from each other, but a single very perfect representation of the pyramid of solid wire, of which the upper part will appear clearly to be at least an inch nearer to the eye than the bottom.

To say that two eyes viewing the same object have on their retinas images differing from each other, according to the laws of perspective, just as in two camera obscuras placed side by side, like the eyes, pictures of the same object differ—and that the images in the eyes coalesce in some way, so as to give to the person a clear perception of the solidity and shape of the object—to say this, is to state the fact, and not to explain it. If it be added, however, according to the details given in Art. 866, that the two eyes see at one time, singly and clearly, so as to judge of its distance by the required degree of convergence of the optical axes, only the one point of the object then looked at, while the other points appear indistinct or double, and that by then changing quickly the direction and convergence of the axes to the other points, the distances and positions of all are noted; the required explanation is thus afforded.

868. For stereoscopic representations two pictures are required

To draw these correctly, according to the principles of perspective for complex objects, such as a landscape or the human countenance, is so difficult, that if the camera obscura and photography, which give such drawings at once, had not been invented, the stereoscope would have been little used. The eyes find the two views of an object required, presented in the object itself, and therefore in the same place. The two views made for the stereoscope, are caused to be seen as if together or mingled, by mirrors or by lenses—the one is called the reflecting, the other the lenticular or refracting stereoscope. By reversing the position of stereoscopic pictures from right to left, the protuberant parts of objects appear depressions and *vice versâ*. The prominent pyramid above sketched, if so used, will appear a hollow or of a cave-like shape. Such a change is called *pseudoscopic* (ψευδης, false).

The stereoscope proves to us that each eye sees an object adapted to its own axis of vision, and that the perfect form or perspective of the object, results from the union of the two pictures by a mental operation. In the annexed figure, representing a section of a railway tunnel (fig. 212), it will be seen that the distant opening of the tunnel, is to the left of the centre on the left side, A, and to the right on the right side, B, the perspective lines inclining accordingly. When viewed at about four inches from the page three engravings will appear, the central one being mentally compounded of the other two, and representing the distant opening and the perspective lines exactly in the centre. On shutting either eye, the central image will disappear, and two only will be seen as they are represented on the page.

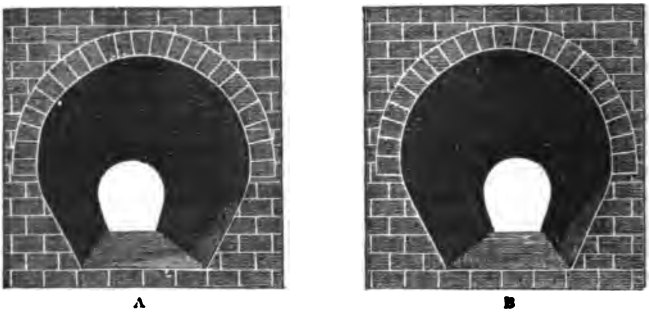


Fig. 212.

A similar effect is produced by coloured objects. In a stereoscopic drawing a table-cover, coloured red on one side and blue on the other, presents a shot colour, or mixture of the two, when viewed by both eyes, but red or blue only when seen by one.

869. When a picture on a plane surface has to represent objects supposed far from the eyé, the farther the picture itself is placed from the eye, supposing the figures to be made of a size duly proportioned, the more perfect will the illusion become, because the divergence of rays and convergence of the axes (two circumstances in which the effect of a mere picture on the eye must always differ from the effect of a real scene) will be more nearly what occurs in nature. This explains in part why the picture called panorama (from Greek words, signifying a *view* of *the whole*) is an exhibition so pleasing. The painting is removed to a considerable distance from the eye, and the near objects are drawn on a proportionately large scale, causing the eyes to feel that the light comes from a considerable distance, and that their axes do not need to approximate or converge much. When, in such a case, the first impression of the want of absolute conformity to nature has passed away, the illusion becomes nearly complete. Another important peculiarity in the panorama is, that instead of being a painting on a plane surface, like common pictures, of which the sides are more distant from the eyes than the centre, and which embraces only a small part of the whole sphere of view, it is on a curved concave surface entirely surrounding the spectator, and on which all the objects visible in various directions from the supposed point of view, are seen in the very situations which in nature they hold; and the spectator is enabled to conceive much more distinctly of each particular by seeing it in relation to the others around. Few persons can forget the vivid impressions of surprise and pleasure made on them by the first panorama which they visited; and after increased experience and more enlightened judgment, they will discover still additional reasons for admiring this marvellous mode of being instantly transported to any distance, to contemplate at leisure some interesting scene, represented under the most favourable circumstances of point of view, light, and weather.

It corrects slight remaining optical defects of a common panorama to view it through a large lens, of which the focal distance is equal to the distance of the picture from the eye. This has the effect of diminishing the divergence of the luminous rays until it becomes exactly what belongs to the supposed remoteness of the objects, and it also bends the whole beams of light so that the axes of the eyes may be nearly parallel.

870. The effects of the magnitude and distance of the ordinary large panoramic views may, with the assistance of suitable glasses, be obtained from even a very small picture or engraved representation embracing the same field. An enterprising artist might undertake to offer for sale a variety of such views at little cost. A common panorama picture, covering a circular wall of 100 feet in circumference and many feet high, may be reduced, still retaining the same truth of proportions, to appear as an engraving on paper five feet long and eight inches high. With the arts of lithography and photography now so well adapted for producing soft representations of scenery, the expense of such views might be rendered so moderate as to allow of their becoming a common part of library furniture. When we reflect upon the expansion of thought obtained by travelling, and that not a few of the advantages of travelling would follow a familiarity with a good selection of panoramic views, it appears that courses of instruction in geography and history may be more commonly illustrated than now, by this very interesting mode of aiding the conception and memory. This want has been in some measure supplied by photography.

Common paintings and prints may be considered as detached parts of a panoramic representation, showing as much of that general sphere of vision which always surrounds a spectator, as can be seen by the eye kept in one place, and looking through one window or other opening of moderate size. The pleasure from contemplating these, is much increased by using with them a lens or such spectacles as above described.

The stereoscopic landscape views on glass, now become common, surpass all other representations of real scenes in being mathematically and minutely accurate, and in the curious fact, due to the double pictures, that objects behind hidden from one eye by objects in front are visible to the other eye.

871. An interesting kind of representation has been exhibited in London and Paris under the title of *Cosmorama* (from Greek words signifying *sights of the world*, because of the great variety of views). Pictures of moderate size are placed outside of what appear ordinary windows in a darkened room, but which are really large convex lenses fitted to correct the errors of appearance which the nearness of the pictures beyond them would else produce. Then, by the addition of various subordinate contrivances, calculated to aid and heighten the effects, they lead even shrewd judges to suppose the pictures of moderate size behind the glasses to be large elaborate works. To children they appear as magical realizations of natural scenes and objects.

From what has now been said, it appears that for the purpose of representing still-nature, or mere momentary states of moving objects, a picture truly drawn, truly coloured, and which is either large, to correct the divergence of light and convergence of visual axes, or if small, is viewed through a proper lens, would affect the retina almost exactly as the realities. But the desideratum remained of being able to paint motion Now this, too, has been attempted, and in some cases with singular success, chiefly by making the picture transparent, and throwing lights and shadows upon it from behind. In the exhibitions of the *Diorama* and *Cosmorama* there have been thus represented with admirable truth, such phenomena as the clear sunlight of a summer's day occasionally interrupted by passing clouds ; the gradual rising and disappearing of a mist over a wide landscape ; running water, as pouring down in the mighty Falls of Niagara, or the still loftier cascades among precipices of Alpine regions, and even the appalling spectacle of a furious conflagration. One part of the mechanism which produced these effects was a circular frame of canvas turning slowly as a wheel behind the main picture, on which canvas strongly illuminated from the back were painted forms of flame and smoke.

The invention in our day of the stereoscope, and some other discoveries made regarding light and vision, as in photography, have added a new interest to this department of natural philosophy, and may lead to further improvements in the painter's art. Of many objects and subjects, knowledge can be conveyed more quickly and completely by pictorial images than by words, and as things differ so much in their nature, distinct classes of artists have arisen to represent them. There are special painters of flowers and fruit, of birds and of other animals, of landscapes, sea-pieces, and the interiors of buildings, and especially of the human countenance and form, singly in portraits, and conjointly in scenes of human action, as related in history. To attain moderate proficiency in some of these departments, moderate ability suffices, but to reach excellence in others, the highest natural endowments of intellect and feeling, with educational cultivation, are required.

> "*When the image formed, as above described, beyond a lens, is viewed in the air by an eye placed still farther beyond in the same direction, the arrangement, according to minor circumstances, constitutes either the* TELESCOPE *or the* MICROSCOPE."

872. The name TELESCOPE (a compound Greek term, signifying to *see far*, as *microscope* signifies to *see* what is *small*), applies to that marvellous instrument of comparatively modern invention, by the use of which the intelligent mind may be said, on the beams of light as a path, to bound widely into space for the purpose of examining more closely the great distant bodies of creation; or, by which it seems able to command distant objects instantly to approach, for the purpose of convenient inspection. The telescope is the instrument by which this is effected. One which merely doubles the apparent diameter shows the moon exactly as she would appear to a person who had ascended towards her from the earth through a distance of 120,000 miles, while one of greater power produces effects correspondingly great. But to examine the heavenly bodies is only one of the many uses of the telescope. The instrument, fixed on the graduated brass circle of the theodolite, enables us to measure angles, which tell the exact distance of one mountain summit from another, even if a river or a wide sea intervene. Again, men have often wished to discover what is passing at a distance on the surface of the earth around them. Thus, by a telescope, the military chief may obtain a close view of approaching friends or foes while they are yet concealed from the naked eye in the blue mist of distance; and similarly, the sea-captain, while persons around him perceive only a small dark speck on the far horizon, discovers that to be a ship of a class and nation at once evident to him, and with the crew of which, by the additional use of signal flags, he is enabled readily to communicate. At midnight, a telescope directed to a distant cathedral tower may watch on the clock-face the motion of the hands marking the unceasing lapse of time. A man placed in the midst of a wide plain, or on a lofty hill-top, or far on the face of a lake, who might suppose himself quite alone and unseen, might yet, through a telescope, be instantly placed under the observation of any one choosing to watch him. The same might happen to a man within the high walls of his own garden, or even within his house, near an open window, if a straight line could pass from him to an observer.

Now the telescope, with its marvellous powers mentioned, exhibits but a modificaton of the simple case, described in Art. 816, and exemplified in the camera obscura, of an image formed for visual inspection, by the rays of light gathered to a focus beyond a lens. We have here to explain that its powers depend on the two facts, first, of its large lens collecting for the formation of the image (subsequently transferred to the observer's retina) a thousand times or more the quantity of light which the naked pupil admits; and, second, of its forming by this light a large bright image, to which the eye may approach very near, to examine it through a magnifying glass of any power.

873. To understand this fully, we must recall, as explained in Art. 846, that the nature of the bending of light in passing through a lens is such, that all the rays reaching the lens from any point of a visible object in front (as the point A of the cross, A B, fig. 213), and forming what is called a *pencil or cone of light*, are collected in a corresponding point, as *a*, at the focal distance beyond the centre of the lens, so as to meet the central ray of the pencil (here the direct line, A *a*); and then, because the same happens to the light from every visible point of the object, the collected light from all received on a white screen placed there, produces a beautiful inverted image of the object. In fig. 213, to prevent confusion, the rays from the extreme points, A and B, are alone represented. If no screen be interposed in the place where the rays meet to show this image, the rays, although not seen, are not lost there or disturbed, but merely cross in the air and pass on, diverging again beyond the focal points, or towards *c*, as they originally did from the several points of the object itself. An eye, therefore, placed beyond *c*, in the line of the rays, must receive the light from every point of the image, and will see the image in the air as it would see an object situated where the image is. This fact is tested at once by holding a spectacle glass or any lens at a proper distance from the eye between an object and the eye. An inverted image of the object is seen.

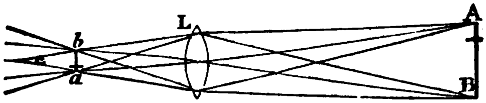


Fig. 213.

874. A telescope, then, is merely a tube, converted into a dark chamber by excluding useless light, and having a large lens, called the *object glass*, filling its distant end like a window, through which the light from the objects in front enters, to form images towards the other end of the tube, where the eye may conveniently inspect them. The inspection of the image is made through another lens called the *eye-piece* of the telescope, which is fixed in a small tube made to slide backwards and forwards in the larger, so as to admit of the focal distances being adjusted to the power of different eyes. The accompanying figure (fig. 214), in which, for the sake of simplicity, the external tube of the telescope does not appear, shows the progress of the light from points of the object, A, through the object-glass, L, to form an image at *b a*, and afterwards to be bent by the eye-piece, D, so as to enter the pupil of the eye at E, where the rays cross, to form the last magnified image on the retina.

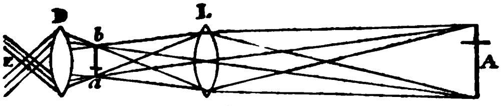


Fig. 214.

In the simple telescope, having only two lenses, as above represented, and called the *astronomical telescope*, or sometimes the *night-glass*, when used by mariners at night, the image is inverted. This circumstance is of no importance in viewing the heavenly bodies, which are round, from whatever side seen. To fit the telescope, however, for viewing terrestrial objects, it is necessary to place in the tube another simple or compound lens, D, which shall turn the inverted image formed by the great object-glass into an image which is upright. There is considerable loss of light where it is necessary to multiply lenses.

875. In order to determine the magnifying power of a telescope, or how much larger an object will appear when viewed through a telescope with an object-glass of three feet focus, than when viewed by the naked eye, we must recollect that the image is formed in the focus of the object-glass, or at *b a*, in fig. 214, and subtends from the centre of that glass or lens the same visual angle as the object itself, viewed from the same point (a fact explained in Art. 820), and to an eye placed at the lens would appear of the same size as the object; but if the eye be brought nearer to the image than the centre of the object-glass, L, the image will appear in proportion just so much taller and broader, and thus, as compared with the object, may be called so much magnified. Now, as the naked eye cannot see distinctly an object nearer to it than at about six inches distance, because of the great divergence of light from nearer radiant points, the telescope in question, without an eye-glass, would allow the eye to come only six times nearer to the image than when at the centre of the object-glass, L, and would only magnify the diameter six times; but if, then, an eye-glass, as D, of half an inch focus, be placed half an inch from the image, so as to render the rays of every pencil nearly parallel, and therefore accommodated to the power of the eye, an eye placed to receive in its pupil the crossing pencils must see the image as large as if it were at half an inch from it, and therefore 72 times nearer than if viewed from the object-glass, and, therefore, again, as of 72 times greater diameter. Now, as in all cases, the image in a telescope is in the focus both of the object-glass and eye-glass, and is therefore nearer to the latter than to the former in proportion as their focal distances differ, the magnifying power is measured by that difference—in the case at present supposed the difference is as 72 to 1, and 72 is the magnifying power of the telescope. The rule is generally thus expressed: "divide the focal distance of the object-glass by that of the eye-glass, and the quotient is the magnifying power." It is always to be remembered, however, that if the diameter of an object be magnified ten times, the surface or area is magnified as the square of the diameter, or 100 times, and so in proportion for other numbers.*

With such means of aiding the sight, then, we can ascertain the light and dark patches seen by the naked eye on the face of the moon to be heights and depressions, or mountains and valleys, and can even estimate the altitudes and depths of these by the measurement of the deep shadows which they cast; we can see the four beautiful moons of the planet Jupiter; we can perceive marks and irregularities on the surfaces of the other planets, enabling us to say at what rate they severally rotate on their axes, experiencing the changes of day and night like the earth:—and we can determine many other interesting particulars of a similar kind.

The discovery of the telescope is said to have been first made accidentally by the children of a Dutch spectacle-maker, while playing with their father's work; but it was applied to no use until Galileo was able to appreciate its worth, and obtained from it the most important results.

876. The *Galilean telescope* was simply a large object-glass to collect much light, with a small concave eye-glass placed so as to intercept the converging rays before they reached their focus, and to change their convergency into the parallelism which the eye could command. This telescope, although magnifying so much less than that formed of two convex glasses, as above described, had still power to verify great fundamental facts in astronomy.*

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* Mr. Tomlinson states that the magnifying power of a telescope may be found by pointing it to a brick wall and fixing it firmly. By looking with one eye through the telescope, and with the other along its side, we may count how many courses of bricks seen by the naked eye are comprised in the height of one course seen through the telescope.

It has been elsewhere explained that a beam of light, in being much bent or refracted by transparent media, as by a strong simple lens, is at the same time resolved into rays of the different colours seen in the rainbow. Hence an image formed beyond such a lens, has coloured edges or fringes. This fact rendered the images of objects, in the first-made telescopes, if much magnified, indistinct; and, but for the important discovery made by Dollond, the optician (Art. 813), that different kinds of glass have *dispersive* and *refractive* powers of different relative force, so that a concave lens of a certain curve applied to a convex lens can completely counteract the dispersion of colours by the latter, while it leaves enough of the convergence of the rays for the formation of an image—refracting telescopes must have always been imperfect. Dollond called his telescopes *achromatic*, or *not-colouring*. It is remarkable that he had the fortune to obtain some glass for his purposes more suitable than any which could with certainty be manufactured for years after.†

877. The *Single Microscope*, represented by the Stanhope lens, is merely a double convex lens, with the margin cut off, and it magnifies, as already explained, chiefly by allowing the eye to be brought much nearer to the object than the distance at which the object could be seen without a lens glass; but even where the relative distance of the eye and object is changed, a lens interposed at its focal distance from the object will still magnify by bending the light, as seen at *d* and *f* (fig. 215), making that which comes to the eye at *e* from the top of such an object as the little cross, *a*, to appear to come from *b*, and that from the bottom to come from *c*, thus causing the cross here represented by the black lines to appear of the size represented by the dotted lines. A concave lens diminishes the size for the contrary reason. A good single lens, or simple microscope, is of great importance in many of the trades and transactions of business. By its aid the detection of cheap mixtures in cloth fabrics is often effected, when they are so dexterously interwoven as to escape the scrutiny of the unaided eye. By the seedsman and florist it is constantly used to recognize tiny seeds, or to detect adulterations. By the watchmaker it is employed to inspect the movements of the minute mechanisms with which he has to deal. It enables the photographer to obtain a most accurate focus on the ground-glass screen of his camera; and by the physician it is used for a variety of purposes; thus, in combination with a hollow mirror, which throws a strong light through the lens, it enables him to inspect the interior of the eye, and reveal irregularities of structure, such as may lead to discovery of the disease from which a patient is suffering. It is used in a somewhat similar way to inspect the larynx or back part of the throat. The technical names, *Ophthalmoscope* and *Laryngoscope* are given to these two optical contrivances.

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* The Galilean telescope renders objects very clear and distinct so far as its magnifying power extends; but its field, with high powers, is very small. It is now almost exclusively used for opera-glasses.

† The largest achromatic telescopes, such as those at Dorpat and Kensington, had each a clear opening of thirteen inches, while that of Lord Rosse's reflector is six feet. Taking the diameter of the pupil of the eye at one-eighth of an inch, the two former instruments admit 10,816 times, and the latter 331,776 times, the quantity of light which is received from any object by the unassisted eye. But as every speculum loses about half the light that it receives, the latter number must be reduced to 165,888. These numbers show how much the area of any object may be magnified by these telescopes, without rendering it less bright than it appears to be to the naked eye, and their square roots, 104 and 407, show their magnifying powers in such a case. (Tomlinson).

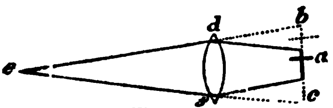

Fig. 215.

878. The *Compound Microscope* is a combination of two or more lenses, whereby a minute object can be more conveniently examined as well as more highly magnified than by a single lens. A useful form of this microscope is shown in fig. 216. The object, mounted on a slip of glass, S, is laid on the plate, P, which has a circular opening to admit the light reflected by the mirror, M, from a lamp or other source of light. The object glass, O, consists of three

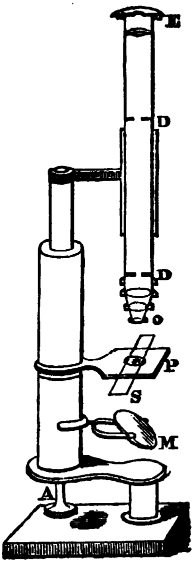

Fig. 216.

lenses of very short focus; and the ocular, or eye-piece, E, is formed of an achromatic or colourless combination of lenses. By means of a pin, A, the tube can be moved up or down, so as to get the object in focus for inspection. A couple of blackened diaphragms, D D, serve to cut off all but the central or useful rays from the object, and to prevent internal reflections in the tube.

There are few greater gratifications than to explore objects with the microscope. While the telescope lifts the mind to the contemplation of boundless space occupied by myriads of suns, and proves this globe of ours, as compared with the universe around it, to be little more than a leaf compared with a forest, or a grain of sand compared with what lies on the sea-shore; the microscope, on the other hand, excites wonder by showing on a leaf, or in a drop of water in which the leaf has been infused, thousands of living creatures, totally invisible to our naked eye, yet not imperfect because so small, but endowed with organs and parts as duly proportioned to each other, as those of an elephant. Living and moving animalcula, not more than the twenty-thousandth of an inch in diameter, may be thus distinctly seen, and their structure determined. He who has admired the orderly formation of a honey-comb may now look through the microscope upon a thin section of wood, and therein see minute arrangements of cells of a still more wonderful kind; or he may compare the lace of an insect's wing with the most perfect fabric which human art can weave. The conclusion which he may probably be led to derive from this comparative examination of the works of Nature and Art will be that the more any natural object is magnified, the more delicate and perfect will its structure appear, while the product of human art becomes thereby coarser and less perfect.

879. The *compound microscope* of great power approaches remarkably, in its structure, to the *telescope*, but while in the telescope a large distant object forms in the focus of the large object-glass, an image exactly as much smaller than itself as the distance of the image from the glass is less than that of the object,—in the microscope, conversely, a small object placed near the focus of a small object-glass produces a more distant image, as much larger than itself as the image is more distant than it from the object-glass,—and in both cases the images are viewed through an appropriate eye-glass. The object-glass in the telescope is large; in the microscope it is very small. If, in the latter, an object-glass be used of one-eighth of an inch focal distance, and the object be so placed that its image is formed at six inches, the image will be in diameter 48 times as great as the object, or will have nearly 2300 times as much surface; and if that image be viewed through an eye-glass of half an inch focus, it will appear still twelve times larger.

> "*Rays of light falling on very smooth or polished surfaces are changed in direction or reflected so nearly in the order in which they fall, as to appear to the eye receiving them, to come directly from objects originally emitting them. Such surfaces are called* MIRRORS; *the surface, which is flat as well as polished, being called a plane mirror.*"

880. The law of mirror-reflection is the same as that of an elastic ball rebounding from a hard surface. An elastic ball falling directly, or at right angles, on a level floor, rebounds directly upwards in the line of its fall; but if it descend obliquely or slantingly from any side, it will rebound then with a similar obliquity on the other side. An illustrative experiment can be made with more precision on a level billiard-table, thus. Let M R (fig. 217), represent the side of the table, and let a billiard-ball strike M R perpendicularly at the point C, from the position *p*, in the line, *p* C, it will rebound in the same line from C to *p*. If the ball be then shot obliquely towards C, in the line, A C, it will rebound just as obliquely from C to *a*, on the opposite side of the perpendicular, *p* C. The angle, A C *p*, is called the angle of approach or incidence, and the angle, *p* C *a*, is called the angle of return or of reflection, and these two angles will always be equal to each other, whatever their size. This important law of equal angles of incidence and reflection holds in many other cases, as in the reflection of waves of water from a perpendicular wall, the reflection of sound from a flat echoing surface, and that which now concerns us, the reflection of light from the surface of a plane mirror.

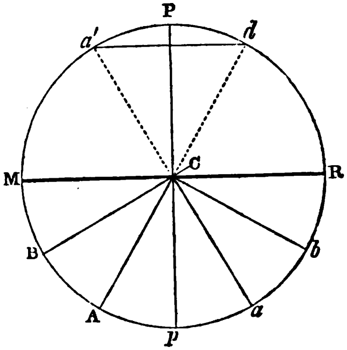

Fig. 217.

If the straight line, M R (fig. 217), be taken to represent a mirror seen edgeways, an eye placed at *p* would see itself as if it were at P, directly beyond the part of the mirror, C, and an eye at *a* would see any object really in the situation, A, as if at *a'*, beyond the point, C, in the line, *a a'*, and similarly for all other positions and directions, the objects before a mirror appearing to eyes before it, as if they were at the same perpendicular distance behind it, as they really are in front of it. When the existence of the mirror is not suspected, the objects in front reflected from it appear to be realities placed beyond it, in lines perpendicular to the surface of the mirror. The reason that an object seen in a plane mirror appears to be just as far beyond the mirror as it is distant on the side of the spectator, is, that the apparent diminution of size, the divergence of the rays of light from it, and the convergence of the optical axes looking at it, all correspond to that supposition.

881. Mirrors placed at the sides of shop-windows make the store of merchandise displayed there appear greater than it really is.

Any smooth plane surface reflects light more or less, and is in fact a mirror; but different substances send back very different proportions of the light which falls on them. A highly-polished metallic surface is the best mirror, often returning three-fourths of the whole light. Hence in reflecting telescopes, the mirror, or ***speculum***, is always made of polished metal.

Our common looking-glasses are really metallic mirrors, for it is the smooth clear surface of the quicksilvered tin-foil behind the glass, which reflects by far the greater part of the light, the glass itself merely serving the purpose of preserving the metallic surface perfectly clean and flat. There is always an imperfection in such glass mirrors, when used for viewing objects obliquely, because the external surface of the glass also acts as a mirror, although much more feebly than the metal behind, and forms a separate image not quite coinciding with the other.

The mirror-power of polished glass alone is seen in the panes of a plate-glass window, particularly where there is a dark background. In the shop-windows of London, passengers on the pavement are often seen studying their own reflected appearance, while appearing to be looking at the wares within. All ordinary sheets of glass, in windows or in picture-frames, reflect much light, but the reflection being irregular where the surface is irregular, the fact scarcely attracts notice.

Plate-glass, highly polished, is an admirable reflector, especially if the space beyond it is somewhat darkened. A few years since, some singular optical illusions were produced by an arrangement of this kind at the Polytechnic Institution. A woman dressed in white clothing, strongly illuminated by artificial light, but concealed from the view of the spectators, was so placed as to have her image reflected from a large sheet of plate-glass, of which the margins were covered or concealed by drapery. The figure might be made to appear standing or sitting in any part of the room, even beyond the glass, and as far behind it as she was placed in front of it. So perfect was the illusion, that it was difficult to believe that what was seen, depended merely on reflected light, until, by cutting off the reflection, the figure suddenly disappeared. These optical ghosts for a time created a great sensation.

882. Those rays which fall with the greatest obliquity on transparent sheets of plate-glass are most reflected, but the objects from which the rays emanate, are not seen unless much of the light behind the reflecting surface is cut off. It might be supposed that the rays of light would be in all cases reflected without undergoing any change of properties, but herein we meet with a very remarkable phenomenon. Light reflected from glass or any non-metallic surface, such as water, is polarized, and acquires properties entirely distinct from those possessed by the incident rays. All the rays reflected at a certain angle, which for glass is 56°·45, are changed in properties, and this always extends, but in a less degree, as the incident rays deviate from this angle. In all reflected light, some polarized rays are to be found—hence this change becomes a test of reflection. It enables the physicist to determine that the light of the moon and planets is reflected, while that of the fixed stars is not reflected—those bodies being, like the sun, self-luminous.

The smooth surface of a liquid is a mirror, and in primitive times was the only kind of mirror known. It is, moreover, horizontal. If the liquid is dark, coloured objects are strongly reflected from it. When the liquid surface is metallic, as of mercury, the mirror is perfect. The mirror of liquid quicksilver is often used by astronomers in observing the apparent altitudes of the heavenly bodies. Because the image in the mirror appears exactly as much below the horizon as the object is really above it, half the distance between them marks the true horizontal level.

883. A varnished picture is a mirror, by reason of its glossy layer of varnish, and if placed so as to reflect strongly the light of a window or of the sky, it prevents spectators from seeing the subject of the picture. Even a highly-polished table of mahogany, or other wood, is a mirror, as is well known among playful children, by the reflections of their own faces, or of wine-glasses and other objects on the table. Polished stones, as marble slabs, and smoothly-painted walls, reflect considerably. Even a surface of air may act as a mirror, as where a cold and dense stratum happens to lie in contact with a warmer and rarer stratum. In such cases, where different levels of the atmosphere have become unequally heated, a partial reflection of objects may take place, producing the optical illusion known as mirage (Art. 810, p. 579).

Many persons do not observe that, in looking at themselves in a mirror, the right side of the image shows the left side of the person. A blemish in the right eye of the spectator appears in the left of the image. A man presenting his right hand towards the image is met by a left hand from behind the glass. The effect is strikingly seen when a printed page is held up before a mirror. Letters and figures assume a reversed position.

It is on this account that a careless artist, painting his own portrait from a mirror, may reverse all the peculiarities which are not the same on both sides; and if, as is often true, one eye is a little higher than the other, or the nose is not quite in the middle, a very incorrect resemblance will be produced. Hence, also, a person whose countenance is at all thus irregular, never sees himself in a mirror as he appears to others; and a belle or a beau, who has decided that a curl is more graceful on the left temple, may unconsciously leave it on the right.

By an image, however, which is reflected from a first mirror to a second, and from that to the eye, persons may see themselves, if they choose, as others see them.

884. A chandelier with lighted candles, placed between two parallel mirrors fixed on opposite sides of a room, makes visible in either glass to a spectator placed on one side an endless straight line of lights. If the glasses are inclined to each other, the lights will appear as if placed in the circumference of a circle, of which the centre is where the mirrors, if prolonged, would meet; this fact is well illustrated in the beautiful toy called the *kaleidoscope.* It is possible to place a few mirrors in such situations around an apartment, that a man entering it may see himself multiplied into a crowd, and a few ornamental pillars may appear in the form of endless colonnades.

There are few more amusing toys than two small mirrors, united like the boards of a thin book, with the leaves removed. This set up edgeways on a table, with some objects placed between the mirrors, when opened at different angles, affords endless amusement, illustrating the law of mirror reflections.

A candle placed between two parallel mirrors, fixed on opposite sides of a room, makes visible an endless row of lights in either glass from successive reflections of the light. Fig. 218 will give an idea of this multiplication of images by parallel mirrors. The light of a star, 1, falling on the mirror, A B, produces, by the law of reflection, just explained, the image, 2; rebounding to the mirror, C D, it produces there the image, 3, in the line of which it is reflected to fall again on A B, and produce the image, 4, and so on. The thick line traces the light which forms the first image in A B, in its zig-zag course between the mirrors, while the light line shows the reflected path of the light forming the first image in C D.

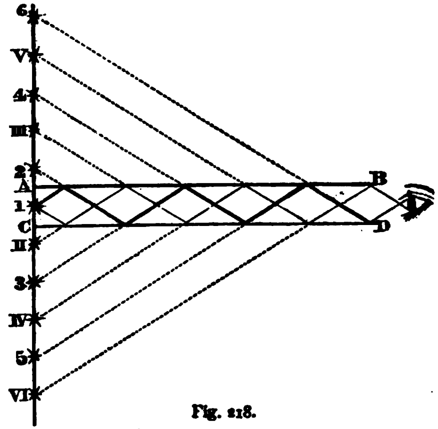

Fig. 218.

In this way the eye may see, as in the figure, ten or more images, instead of the direct single image of any object.

885. The multiplication of images by the use of two or more mirrors placed at an angle and united at the edges, has long been known. Baptiste Porta, in his book called 'Natural Magic,' describes what he considered a very entertaining piece of optical apparatus; it consisted of ten mirrors placed within a box so as to form a ten-sided figure (or polygon), with an opening between the last two for inspection of the effect. On placing a column, or picture, or small image within, the spectator was astonished to behold not one, but a countless multitude, of images mingled in indescribable confusion.

It was reserved, however, for Dr. (afterwards Sir) David Brewster, to deduce the principles of the symmetrical formation of images by inclined mirrors, and to replace the show-box of Baptiste Porta by his charming invention of the kalcidoscope, which has now become a popular optical toy.

886. *The Kaleidoscope.*—The kaleidoscope consists of two pieces of silvered or varnished glass, about an inch broad, and six or seven inches long, enclosed within a suitable tube, so as to have their reflecting faces inclined to each other at an angle which forms some *even aliquot or exact* part of a whole circle, such as 30°, 36°, 45°, 60°, &c. If A O and B O (fig. 219), be two mirrors inclined at an angle of 60°, then five successive reflections will, with the sector, A O B, complete the circle: and any object, such as an arrow, placed obliquely between A O and B O, will appear a star-shaped figure, as in the diagram.

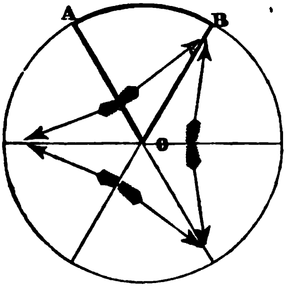

Fig. 219.

The reflections of small fragments of coloured glass placed between plates of glass at the further end of such an instrument, form exquisitely beautiful and perfectly symmetrical patterns, whose form can be varied in an infinite number of ways. If these plates be united in the form of an equilateral or equal-sided triangle, the number of images is increased threefold, as each pair of plates forms a distinct kaleidoscope, as above explained. It has been turned to practical use as an aid to designers of regular patterns, such as are used in carpets, floor-cloths, and wall-papers. By the adjustment of a lens at the end of the tube in place of the receptacle for the fragments of broken glass, all natural objects may be converted into perfectly symmetrical figures. When this instrument, which is called a *kineatiscope*, is directed to a bed of flowers or a group of coloured silks or woollens, they are brought to a focus on the mirrors, and are then multiplied by reflection into the most beautiful symmetrical patterns, which are changed by the slightest movement of the tube.

887. The sun or moon reflected in a still lake, appear exactly as they do in the sky; but if the surface of the water is raised into waves by the wind, instead of one distinct image, there will be a long line of bright tremulous reflections; the reason of the appearance being, that every little wave, to a considerable distance, has some part of its rounded surface with the direction or obliquity which, according to the required relation of the angles of incidence and reflection, fits it to reflect the light to the eye, and hence every wave in that extent is sending its momentary gleam, creating a long patterning of reflected light over the waters. Summer visitors from the interior of a country to a southern coast, as from London to Brighton, often express wonder at the great difference of climate, or the heat and light encountered when they walk along the cliffs, forgetting that in the reflection from the sea, they have almost a double sun.

> "*Mirrors may be plane, convex, or concave; and certain curvatures will produce images by reflection, just as lenses produce images by refraction; in consequence there are reflecting telescopes and microscopes, as there are refracting instruments of the same names.*"

888. While a plane surface reflects light, so that what is called the image in it of a known object in front, may readily be mistaken for the reality, convex or concave mirrors reflect as if every distinct point of them were a separate exceedingly small plane mirror, and their effects on light depend on the relative inclination of the different parts. The forms of importance are the regularly spherical and the parabolic concave, and convex mirrors. These produce on light, effects similar to those of lenses, only the concave mirror answers to the convex lens, and the convex mirror to the concave lens. It is the concave mirror, as a speculum, which gathers the light to form the images in the most powerful telescopes that exist, as those of Herschel, Lord Rosse, and others. Admirable as is the refracting telescope, it still falls short in certain respects of the telescope acting by reflection.

In a hollow sphere, or part of a sphere with polished internal surface, if rays radiate from the centre in all directions, they reach every part perpendicularly, and therefore are thrown back to the centre. Thus, if A B (fig. 220) were part of a concave spherical mirror, of which C were the centre, rays issuing from C would, in obedience to the law that "the angles of incidence and reflection are equal," again meet at C.

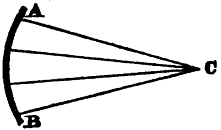

Fig. 220.

It can be proved also, that any ray parallel to the axis of the mirror, falling upon such a mirror, will be reflected inwards so as to cut the axis half-way between the mirror and its centre, *viz.*, at D, the centre being C; and that as all parallel rays meet after reflection in the same point, that point becomes a focus, as already explained for lenses, and there, when the mirror is held towards the sun, an image of the sun will be formed, as in the focus of a lens. This point is called *the focus*, or the *principal focus* of the mirror.

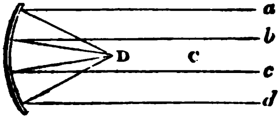

Fig. 221.

For the same reason that parallel rays, when reflected, meet in the focus, so will rays, issuing from the focus towards the mirror, become parallel, after reflection, as seen above (fig. 221); and if they be then caught in a second and opposite mirror, as represented at p. 433, corresponding effects will follow.

889. Now, as already explained for a lens, in whatever direction a pencil or cone of rays may fall upon a concave mirror, they are equally brought to a focus somewhere in the line of the central ray of the pencil, and when the rays fall on the mirror with a certain obliquity from one side of its axis, as from A (fig. 222), the central ray of that being A *d*, and the axis of the mirror being C *d*, their focus will be with the same obliquity on the opposite side of the axis as here shown at *a*, in the direction *d a*, following the central ray in its reflection, and therefore the mirror will form an inverted image of any object placed before it, just as a lens does; and the image will be near or distant and large or small, according to the divergence of the approaching rays, exactly as happens with lenses. Thus, the camera obscura, magic lantern, telescopes, and microscopes, may all be formed by mirrors. Moreover, *concave mirrors magnify, and convex mirrors minify*, like lenses of the opposite names. The two subjects, therefore, of images by refraction and by reflection, run so nearly parallel, that it would be useless repetition here to enter upon the detailed consideration of the latter, and it may be sufficient to show, further, why a concave mirror magnifies, and why a convex mirror minifies.

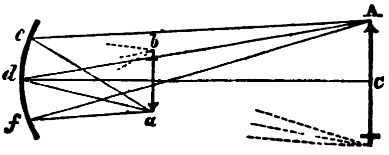

Fig. 222.

A concave mirror magnifies because a ray of light nearly parallel to the axis of the mirror, passing from the top of the cross, A (fig. 223), to the part of the mirror where it will be reflected to an eye placed near the focus, F, seems to the eye to come from C, and the light from B similarly appears to come from D, so that the cross, A B, by the reflection, seems to the eye to be of the greater dimensions, C D.

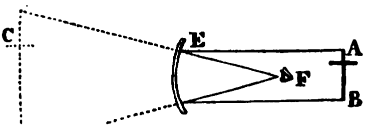

Fig. 223.

890. In a convex mirror, again, for corresponding reasons, the cross, A B (fig. 224), reflected, appears only as C D, and therefore smaller than the reality.

A convex mirror or silvered globe hanging from the wall, is a common ornament in apartments, exhibiting a pleasing miniature of the room and its contents. If placed opposite to a window it gives a pleasing landscape view, in a reduced form, of all that is in front of the house.

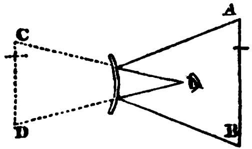

Fig. 224.

The cornea of the human eye is a convex mirror, which portrays most perfect miniatures of a window or any bright object. It is the image of the window, or of the sun in the convex mirror of the eyeball, which painters usually represent by a white spot, sometimes without knowing what it represents; and a similar luminous spot or line must be made when they have to picture almost any of the pieces of furniture which have rounded polished surfaces, such as bottles, glasses, or smooth pillars.

It has been a mathematical amusement to calculate what kind of distortion, mirrors of unusual forms must produce, and then to make distorted drawings, which, when reflected from such mirrors, will produce in the eye the natural form of the objects.

891. When a concave mirror is used for a telescope, the image formed in front of it, to be examined through the magnifying eye-glass, may be viewed in various ways,—first, as in *Herschel's* telescope, by the spectator turning his back to the real object and looking in at the mouth of the telescopic tube, near to the edge of which the image is thrown by a slight inclination of the mirror at its bottom:—or, secondly, as in the *Newtonian* telescope, through an opening in the side of the tube after being reflected by a small plane mirror placed diagonally in the centre of the tube:—or, thirdly, as in the *Gregorian* telescope, through an opening cut in the centre of the principal mirror or speculum, after being reflected towards that opening by a smaller mirror placed in the centre of the tube with its face towards the observer: this last arrangement is that preferred for small telescopes, because the spectator, while seeing the image, is also looking in the direction of the object.

Reflecting telescopes have the advantage of being perfectly *achromatic*, that is, of producing the images quite free from coloured or rainbow edges; for compound light is reflected, although not refracted, entire, all the colours following the one law of equal angles of incidence and reflection.

Herschel's large telescope had a mirror of 48 inches in diameter, and, therefore, to form images, collected about 150,000 times more light than can enter the pupil of an unassisted eye, forming, with that light, at a focal distance of 40 feet, a large image admirably distinct. It was with this telescope that, in the obscurity of remote space, Herschel discovered the immense planet rolling along, which in honour of his royal patron, he called the *Georgium Sidus*, but which now, by the decision of the scientific world, is called Uranus;*—and with this he discovered moons, before unseen, of other planets, and he unravelled many of the celestial nebulæ and clustered stars of the milky way, and, in a word, unveiled, vastly more than had before been done, the system of the boundless universe.

Other steps of advancement have been made since Herschel's time. Lord Rosse constructed a reflecting speculum nearly twice as large as Herschel's; and M. Foucault, of the French Institute, has succeeded with admirable skill in forming good specula or mirrors of glass coated with metal. Lord Rosse's reflector was six feet in diameter. For its magnifying power, as contrasted with some of the largest refracting achromatic telescopes, see note at foot of page 646.

892. *Total reflection.*—Although the external surface of glass reflects but a small part of the light which falls upon it—being therefore a feeble mirror, still, curiously, if light, which has entered a piece of glass, fall *very obliquely* upon the back or internal surface of it, instead of passing out there, it is more perfectly reflected than it would be by the best metallic mirror. Thus, light from A (fig. 225), entering a piece of glass at B, is entirely reflected at C, on the internal back of the piece, and escapes at D towards E.

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* From the Greek *οὐρανος*, signifying the firmament or boundary of Heaven. The planet Neptune has since been discovered at a still greater distance from the sun.

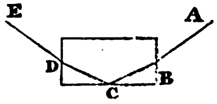

Fig. 225.

The Camera Lucida.—It is this fact which enabled Dr. Wollaston to devise that beautiful little instrument called by him the *Camera Lucida.* The letters, A G C (fig. 226), indicate a piece of glass with a vertical surface, C, and a horizontal surface between C and A. The light entering from an object or scene, F, falls on the oblique surface, D, from which it is reflected to the oblique surface, A, from which it is reflected again to the eye at E, enabling that to see clearly the object at F. The wide pupil of the eye at E can also see past the corner of the glass at A, the sheet of paper on the table below it, B, and at the same time the objects at F, as if traced on the paper. With a lead-pencil that appearance can be made permanent, and a correctly-drawn outline of the scene is at once obtained. This instrument for assisting draughtsmen is still simpler than the camera obscura. Other modifications of it have since been contrived.

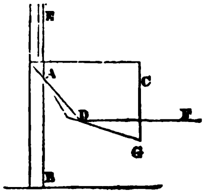

Fig. 226.

893. The same fact of the internal surface of a transparent mass becoming a mirror, furnished at last the explanation of that apparition, so admired before it was understood, and not less admired since, of the *rainbow*, or *arc in the heaven*, as in France and elsewhere it is named—an object which the poets of nature have seemed almost to worship for its beauty.

The Rainbow.—When a partial shower of rain falls on the side of a landscape opposite to that where the sun is shining, there appears in the shower this marvellous arch, red at its external border or confine, and then successively orange, yellow, green, &c. (in the order of the colours of the prismatic spectrum described in Art. 812), towards its inner border. Its centre is directly opposite to the sun, or at the end of a straight line supposed to pass from the sun through the eye of the spectator to a point below the opposite horizon. The diameter of the circle of which the bow is a part, is of nearly 84° of the sphere of view. There is also frequently seen external to this bow a second, having a much fainter light, of greater diameter than the first, and with the colours in a reverse order, *i.e.*, red in the inner and violet on the outer border.

The explanation of this interesting phenomenon is as follows :—While the sun shines upon the spherical drops of falling rain, the light entering the whole central part of any drop passes completely through, but that portion which enters obliquely near the edge of the upper part of the drop, as at *a* (fig. 227), is refracted or bent, and much of it reaches the back surface of the drop at *y* so slantingly, or at such an angle, that it suffers there entire or total reflection (Art. 892), instead of being transmitted; the ray, therefore, is returned to *b*, where it escapes from the drop, and as here shown, descends to the earth or eye in the direction *b e*. Thus every drop of rain on which the sun shines is a little spherical mirror suspended in the sky, and is returning, at certain angles, a portion of the light which falls upon it; and an eye placed in the required direction, receives the reflected light. If in this case, however, there were *reflection* only, and no *refraction* with *separation of colours*, the rainbow would be only a very narrow resplendent arc of white light, formed by millions of little mirrors in the sun; but, in truth, as the light which enters near the edge of the drop, traverses the surface very obliquely, it is much bent or refracted at *a* before its reflection at *y*, and afterwards at *b*, and is divided into rays of its seven colours, as it would be on passing through a prism. (See Art. 812.) In consequence of this division or separation of the light, as it escapes from the drop at *b*, instead of one white ray descending from each drop to a certain point of the earth, seven rays descend (marked by dotted lines from the figure 1 on the left hand to 7, 6, 5, &c., on the right, fig. 228). The separation in the drawing is made greater than occurs in reality, in order to render the fact more evident. Of these coloured rays, an eye can only receive one at a time from the same drop, which drop will then appear of the

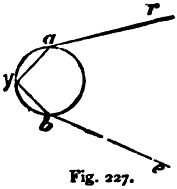

Fig. 227.

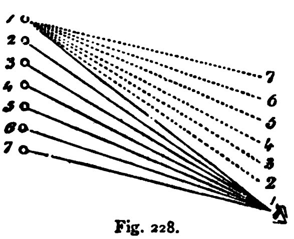

Fig. 228.

colour of the ray; but for the same reason that seven eyes placed in a line from above downwards, as at 7, 6, 5, &c., on the right, would be required to see the seven colours from one drop in the bow, so one eye looking in the direction of seven drops situated in a corresponding row, as from 1 to 7 on the left, will catch the lower or red ray of the upper, the orange or second ray of the next, the yellow or third ray of that which follows, and so on, while it will lose all the others, and thus will see the several drops as if they were each of one colour only. Of such elements, then, found in the same relative directions all around the sky, the arch or bow is constituted. Each colour emerges at a definite angle, and all the drops emitting the red ray at the same angle, will necessarily take the form of a circle or bow, of which the eye of the spectator will be the centre. So of the other colours in their order. If the reader will imagine a cone, of which the apex is in the eye, and the base more or less elevated above the horizon, according to the position of the sun, he will at once comprehend why each colour takes the form of a bow, and why the colours are in concentric layers.

894. The annexed illustration from Pouillet (fig. 229), will show the exact relation of the eye of the spectator to the rays from the sun, incident on and emerging from the drop. O represents the spectator with his back to the sun, and O H a horizontal line passing from the centre of the sun through the eye of the spectator, and carried to infinity towards the east. The line, O T, passing from the eye of the spectator, is carried to infinity in the rain-cloud. This forms, with the horizontal line, O H, an angle of 42° 1′ 40″. Let it be supposed that this second line turns around the first and preserves the same angular relation, it will describe a conical surface, of which the upper half only requires notice. The line in each of its positions will meet with a number of drops of rain, and A B C represents one of these drops. The rays of light which it receives from the centre of the sun are horizontal, and parallel to O H. The ray

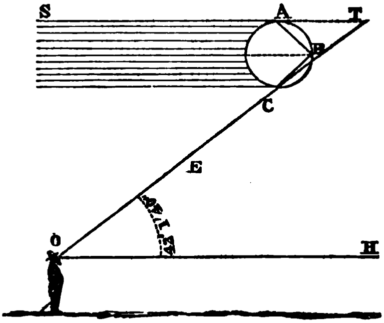

Fig. 229.

S A, after having undergone refraction in A, reflection in B, and a second refraction in C, issues from the drop in the direction C E, at its maximum angle of deviation; S A being parallel to O H, the angle, S T E, is 42° 1′ 40″, like the angle, E O H. Under these conditions the spectator will see the red ray only in the drop, and in all the drops equidistant from the eye of the spectator.

Just as no circle can have two centres, so no two persons can see the same rainbow. Even one person by looking separately with his two eyes sees two different bows, and the same eye does not for two instants, receive coloured rays from the same drops.

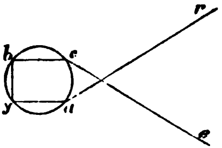

Fig. 230.

895. We have here described what is called the inner or principal bow, formed in the drops by two refractions, and one reflection, of light. To produce the fainter second or outer bow, mentioned above, and of which the colours are in a reverse order, the light which enters on the under size of the drop, as at *a*, is reflected first at *y*, then again at *b*, and escapes at *c* towards the eye, after two reflections, as well as two refractions. Owing to there being two reflections, there is a greater loss of light, and therefore less intensity of colour in the outer bow; and as its diameter is 108°, a portion of it may be visible when the inner bow cannot be seen.

In the outer bow, the colours appear in an inverted order, owing to the rays of light entering the drop from below, while in the inner bow they enter from above. Hence in the outer bow the violet is always on the outside, while in the inner it is on the inside. The reds are, therefore, near to each other in the two bows. The breadth of the outer bow is equal to 3° 10′, nearly three times that of the inner, and the space between the two bows is 8° 57′.

Rainbows are never seen at mid-day, or when the sun is high above the horizon. As the sun, the eye of the spectator, and the centre of the bow are always in a right line, it follows that more than a semicircle can never be seen, and this can only be seen at the rising or setting of the sun—this luminary and the centre of the bow being then in a horizontal line. The higher the sun, the smaller the portion of the semicircle seen; and when the sun is more than 42° 18′ above the horizon, the inner or brighter bow entirely disappears, as its centre would then be so many degrees below the horizon. For a similar reason, when the sun has an altitude of 54° 23′, the outer and paler bow is no longer seen.

On some rare occasions a third bow has been seen, but owing to the increased number of reflections which the light then undergoes, the colours have been very faint.

An artificial rainbow may be produced in sunshine at any time by scattering water into drops from a whirling brush or otherwise, on the side away from the sun, at a moderate height; and a rainbow is often seen in the spray of fountains, of a lofty waterfall, or of waves in a storm. The cut-glass ornaments of chandeliers produce colours on the same principle as rain-drops. Mist and particles of frozen water between a luminous body and the eye produce the circular *halos* with little colour often observed round the sun and moon. A *colourless halo* is light reflected from the external surfaces of drops or solid particles.

The Solar Spectrum and Spectrum Analysis.

896. We have already (Art. 812) mentioned the beautiful experiment made by Newton in 1675, of unravelling the thread of white light, and showing it to be really composed of a number of different coloured threads. Since the days of Newton, this decomposition of light has developed into one of the most attractive and instructive subjects in the whole field of physical science. It has become an instrument in the hand of the chemist to detect the existence of metals, where other means of detection would utterly fail; it has even revealed the composition of the sun and fixed stars—a feat in chemistry more incredible, at first appearance, than would be the realization of the wild dream of the alchemist. It is necessary, therefore, that we should enter somewhat more minutely into the experiment of Newton, and spectrum analysis, in connection with the wave or undulatory theory of light.

There are, according to the latter doctrine, incessantly beating upon our globe countless millions of ethereal waves, having their prime source in the sun, and wafting to our world all the life and beauty which it contains. These ether waves are not all of one size and rate of motion, but of very varied length, and of correspondingly varied effect. Waves within the limits of length mentioned (Art. 914) affect the optic nerves producing the sensation of *light;* slower and longer ether waves (within other limits) communicate to ponderable molecules those vibrations which excite in us the sense of *heat;* while, again, ether-waves, within certain higher limits than those of light waves, are specially adapted to excite those atomic changes or motions which are called *chemical.*

897. It follows at once from the conception of wave-motion, and of its being retarded on passing from a rarer to a denser medium, that a prism-shaped dense medium will bend a short rapid wave more out of its original course than a long and slow one. If, then, the ether waves, poured on our earth by the sun, be of different lengths, a little consideration will show that a beam or a bundle of such waves, S P (fig. 231), falling upon a prism, P, will be assorted according to wave-lengths, and displayed in a long strip, V R, of the same breadth as the image of the sun would be, in falling on the screen without refraction. Different lengths of ether-waves exhibit themselves to the eye as the different rainbow colours, violet, indigo, blue, green, yellow, orange, red; but, by special means of detection, it is found that beyond the visible violet rays of the solar spectrum there are invisible rays having a powerful chemical effect, and beyond the red end of the visible spectrum there are invisible waves of ether having a powerful heating effect. It is found that the rays which affect the eye most strongly are not those which affect a sensitised piece of paper most, or which affect a delicate thermometer most.

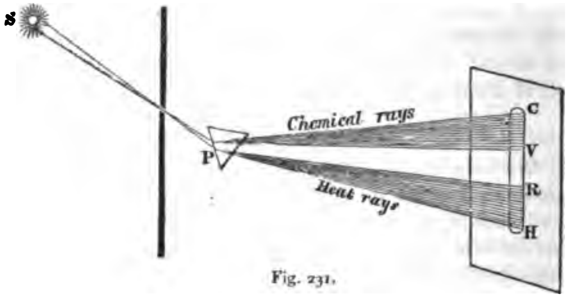

Fig. 231.

898. The diagram (fig. 232) will show how far the spectrum really extends on each side of the visible or coloured spectrum whose dark lines are inserted as an index. It also shows the distribution of the chemical, luminous, and heating power of a beam. The greatest luminous intensity falls near the D or sodium line (see Art. 904); the maximum heating effect lies *outside* the red end of the visible spectrum, while the greatest chemical effect lies in the violet of the opposite end.*

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* Roscoe's 'Spectrum Analysis.'

Speaking generally, we may say that the rays which affect the optic nerve lie midway between the heating and the chemical rays. The more hidden and minute changes, which we call chemical, are thus affected by the more rapid and minute ethereal vibrations; while the long, slow rays of heat appeal to our grosser senses, That there is only a difference in degree, and not in kind, among the different rays, is proved by the following two facts:—(i.) By concentration with a lens the heat-rays may be caused to act upon a solid body and make it *white-hot*, *i.e.*, visible, the slow heat rays being thereby quickened in rapidity, and correspondingly shortened. (ii.) By allowing the invisible chemical rays to fall on certain substances known as *fluorescent*, they are reduced in length and rapidity, and so brought within the pale of the visible.

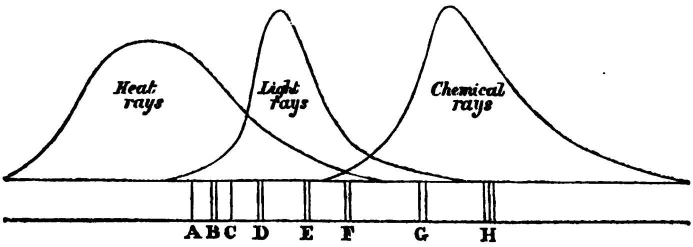

Fig. 232.

899. *Fluorescence.*—As calorescence applies to the red end of the spectrum, so fluorescence is applied to certain phenomena at the violet end. This term has been applied to the internal dispersion of the rays of light on certain solids and fluids. Sulphate of quinine forms with water a perfectly colourless solution, but under certain aspects, it presents at the surface a splendid light-blue colour. Sir J. Herschel noticed this in 1845, and it has been observed in a solution of the bark of the horse-chestnut in water, as well as of the green colouring matter of leaves (*chlorophyll*) in alcohol. It is called fluorescence or epipolization. This property serves to detect the presence of quinine even when the solution is much diluted. Stokes found that the rays causing dispersion, are the invisible rays beyond the violet, those which can be seen in the spectrum by the aid of solution of quinine on paper, or by the use of uranium glass. As these chemical rays are not found in the light emitted from a candle, the fluorescent appearance cannot be well seen by artificial light.

900. *Colour of bodies.*—Coloured bodies, as we term them, possess the power of extinguishing or absorbing certain rays or waves of the solar beams, and reflecting others. A body which reflects all the rays in the same proportion as it receives them is *white;* a body which absorbs all the rays and reflects none is *black.* A red powder, such as the red iodide of mercury, absorbs all the blue and other rays, and reflects the red only; and a red glass stops all the rays excepting the red, sifting them out, and allowing them to pass, as being of a period or temperament conformable with itself. The petal of a scarlet geranium is red, because by its molecular structure it absorbs and fixes all the rays excepting the red. When held in the green rays of the spectrum, it cannot be distinguished from black velvet. That a coloured body exercises this passive or secondary sort of action on the luminous rays, and does not impart to them any new property, is proved by the following experiment: If we place a *red* wafer at the confines of the green and blue part of the spectrum, a *yellow* wafer in the *indigo blue* part, and a *blue* one in the *red* of the spectrum, all three wafers will seem equally black, showing that they are *unable to* reflect the lights which fall on them, or have an atomic constitution which accepts the rate of ethereal pulsation corresponding to the respective colours named, and does not return the motion. The facts seem analogous to the case of the mechanical impacts of ivory balls (see Art. 170). If the impinging ball be of the same weight as the ball it strikes, the motion of the former is accepted and passed on, none being returned; whereas, if the two be of unequal masses, corresponding degrees of the motion will be accepted and returned.

901. *Dark Lines of the Solar Spectrum.*—When the light of the sun, passing through a fine slit, is carefully examined by means of a good prism, it is seen that the coloured spectrum or extended band of light is crossed at frequent intervals by dark lines parallel to the line of the slit. It thus appears that the sun does not transmit to us luminous waves of all varieties of length between the short violet and the long red. There are interruptions corresponding to definite wave-lengths in the solar spectrum, examined by any number and variety of transparent prisms, which we do not find when we examine the light of a candle, or of a gas jet, or of an incandescent wire, by the same means. The *dark lines* in the solar spectrum were first detected by the English philosopher, Wollaston, about the year 1802; but as they were first accurately mapped by the German optician, Fraunhofer, about the year 1814, they are often designated

Fraunhofer's Lines. Wollaston had observed only the principal lines, such as are given in our diagram (fig. 233); but Fraunhofer, by examining the prismatic band through a telescope, counted and mapped accurately down on paper no less than 576, naming the most conspicuous lines by the letters of the alphabet, by which they are still recognized. Thus A is at or near the extreme red end of the spectrum; B is between the red and the orange; C is situated in the orange; D is a double line in the yellow; E is in the green; F, a group of fine lines in the blue; G is just at the confines of the indigo; and H is a host of fine lines in the violet.

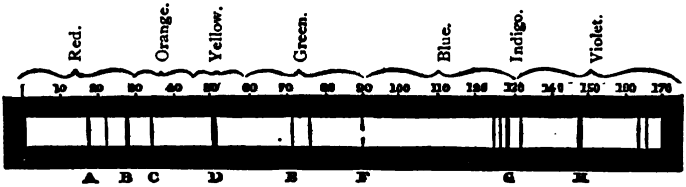

Fig. 233.

Fraunhofer observed, also, that these lines are always present in the same relative positions in sunlight, whether direct or reflected. Thus the light of the moon and of the planets presents exactly the same set of dark lines as the light of the sun, as we should expect, from their being but reflectors of the sun's light. On the other hand the fixed stars, which we know to be independent sources of light, show different groups of lines, with different relative arrangements. Fraunhofer concluded from this that the dark lines, however they may be caused, are not due to any interference of our atmosphere with these ultra-mundane lights.

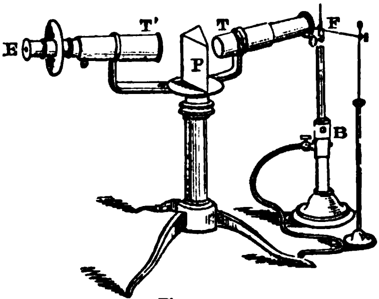

Fig. 234.

902. Fraunhofer's application of the telescope to the examination of the solar spectrum resulted in the construction of the *spectroscope*, an instrument indispensable to the chemical analyst of the present day. The figure (234) will give an idea of its leading features. It consists essentially of a tube, T O, which is provided with a slit at the further end, O, capable of being made larger or smaller by means of a screw. At the other end of the same tube is a *collimator* or lens which throws the light passing through the slit into parallel rays. A second tube, E T′, is a telescope whose focus is adjusted till it gives a distinct image of the slit. On introducing a prism, P, between the two tubes, we must of course move the latter tube round till its axis coincide with the direction of the bent or refracted beam from the slit. We have thus the means of inspecting the prismatic band more minutely, and of distinguishing the dark lines with facility. This instrument also enables us to study the spectra of artificial lights; and by its means we can see in the spectrum of an incandescent gas or vapour, characteristic features which serve for their identification in the case of a compound incandescence.

903. An incandescent solid or liquid placed in front of the slit of the spectroscope, always gives a spectrum unmarked by dark lines. The light of a common gas flame is almost entirely due to the incandescence of the solid carbon particles suspended in the flame; and this is the reason that the spectrum of such a flame is continuous, it being, in fact, not the spectrum of the hydrogen gas at all, but of the carbon particles.

When, however, we examine the flame of a body really in the gaseous or vaporous state, placed in front of the slit of the spectroscope, we find its spectrum is *discontinuous*, consisting usually of a characteristic set of luminous bands of one or more colours. Thus, for instance, if we burn a salt of sodium, such as common salt, which is the chloride of sodium, or common soda, or Glauber's salt (sulphate of sodium), in the flame of a spirit lamp, or of a common Bunsen burner, we volatilize and decompose the salt and obtain, as the spectrum of the burning metallic vapour, a bright yellow line corresponding to the place of the dark D line in the solar spectrum (fig. 233). No other simple substance is found to give the same line; it is consequently assumed to be indicative of the presence of the metal sodium, in some form or other, wherever it appears in the spectrum. The study of spectra has revealed the important fact that there is no substance more universally diffused than sodium; the air is impregnated with it; the very particles of dust seem to be crusted with its salt, for if we strike two books together near a common gas flame at the slit of our spectroscope, we find that the inflamed dust makes the well-known D line flash forth with more or less distinctness. This is doubtless due to tiny particles of salt evaporated from the large surface of salt-water on the face of our globe.

Again, if we examine with the spectroscope the light of the vapour of the metal potassium, or the light obtained from any salt of potassium burning in a Bunsen or other smokeless flame, we see two red bands (occupying the same relative position in the spectrum as the dark A and B lines in the solar spectrum); and also near the farther end of the spectrum we find flashing forth a violet line between the G and H dark lines of the solar spectrum (fig. 235).

904. The adjoining figure (235) will serve to convey, more clearly and briefly than words can do, an idea of the peculiar sets of lines corresponding to the vapours of the two metals we have mentioned, as well as a few others.

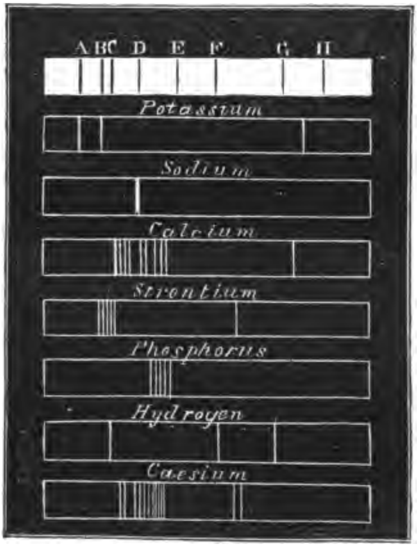

Fig. 235.

Calcium, the metallic base of common lime, gives a number of bands in the orange, yellow, yellowish green, and one bright band in the blue.

Strontium, salts of which are used for giving the beautiful crimson red in fireworks and illuminations, exhibits some very bright lines in the red and orange, and one in the blue, but of greater wave length than the calcium blue.

Phosphorus gives a number of green lines only.

Hydrogen gas a red, a blue, and an indigo-blue band.

The last spectrum in the fig. (235) is interesting as that of one of four rare metals which have been discovered by spectrum analysis, and as having a rather curious history. It was discovered by Professor Bunsen in 1860. When examining by the spectroscope the flame given off by a mixture of salts left from the evaporation of a large quantity of mineral water, he remarked some very bright lines which he was sure did not belong to either the soda or potash of the mineral water. After evaporating the enormous quantity of forty-four tons of this mineral water, he succeeded in separating the new metals, though from this large quantity of water, he had only 200 grains of the mixed metals. To the one he gave the name of *Rubidium*, from its ruby or red lines, which are, however, nearer the heat end of the spectrum than the potash lines. To the other, and the one indicated in the figure, he gave the name of *Cæsium*, from two very characteristic *blue* lines, while it gives also orange lines, and no red lines at all.

A third metal, discovered in 1861 by Crookes, in the same way, is known as *Thallium*, from *thallus* (Lat.), a green bud. Its spectrum consists of a single very distinct green line.

The fourth metal, discovered by a similar process, is known as *Indium*, from its spectrum being composed simply of two lines in the indigo. It was discovered (1864) in some zinc ores by the two German professors, Reich and Richter, of Friburg. (See Roscoe's 'Spectrum Analysis.')

905. To summarize the general results of such spectroscopic examination of incandescent metals, we may say that each metal has its own peculiar set of luminous rays or lines which it gives forth, and that it appears from a most careful examination of these, that there is no overlapping of the lines of one metal with those of another. Copper gives a set of green bands; zinc a set of bright blue and red bands; while brass gives both the copper and zinc lines, so that its composition, if not otherwise known, might in this way be unerringly deduced.

The composition of atmospheric air is revealed by spectroscopic examination of it when a small quantity of it is rendered incandescent by the electric discharge within what is known as a Geissler's tube. The oxygen lines, the nitrogen lines, and the hydrogen lines of the water vapour, always present in greater or less quantity, are all distinctly recognisable by the experienced spectroscopist.

906. The question at once suggests itself—What mean those remarkable dark bands in the solar spectrum, if they correspond exactly in situation with the bright lines peculiar to particular metals, as in many instances they do? Does the dark D line mean that there is no sodium in the composition of the sun? The answer to the question was first given by the German professor Kirchhoff, and involves a new theory of the sun's constitution.

Kirchhoff's theory is founded on the experimental fact that vapours and bodies in general absorb, and consequently fail to transmit, the very luminous rays which they emit when in a state of incandescence. Thus, if the vapour of sodium come between the slit of the prism and a flame impregnated with sodium vapour, and giving forth the characteristic D lines, the ethereal rays of the burning sodium are absorbed by the sodium vapour, and the band is completely cut off. The annexed figure (fig. 236) will serve as an illustration. In the spectrum, A A, the lines, C C, are such as would be produced by the incandescent vapour of sodium; while in the spectrum, B B, they are represented by the dark lines, D D. They are reversed by absorption on being transmitted through another portion of vapour.

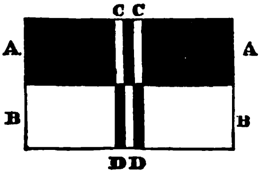

Fig. 236.

The same remarkable phenomena appear with other incandescent metals and their vapours. Thus, too, if sodium vapour be interposed between the flame of a candle, it cuts out the D line and gives us what is known as the *reversed sodium spectrum;* and, if we interpose other incandescent vapours, they will each cut out from the continuous spectrum their own peculiar lines. Here, then, we have the basis of Kirchhoff's theory, that the internal mass of the sun has an intensely white-hot surface, which emits *white* light—that is, light waves of all degrees of refrangibility; but outside of this light sphere or *photosphere,* as it is now usually termed, is an envelope or atmosphere of less hot, but still glowing, gases and vapours, which is called the *chromosphere;* it is composed of the vapours of the different metals, which may exist in a molten state in the photosphere, and exercises the same sifting or absorptive action on the rays issuing from within, as the artificial vapours mentioned above.

907. From the foregoing statements, then, we should infer that sodium, hydrogen, calcium, strontium, iron, and the very rare metal titanium, whose bright lines coincide exactly with dark lines of the solar spectrum, must all be present in the solar vaporous envelope.* The truth of this hypothesis is upheld by the fact that a spectroscopic examination of the reddish protuberances which appear under various shapes in total eclipses of the sun, displays bright lines in positions corresponding to the C (near), D, F, and near G, dark lines of Fraunhofer. This amounts almost to a demonstration of the existence of a gaseous envelope, composed to a great extent, if not principally, of hydrogen, the characteristic dark lines of which are C, F, and one in front of G. (See fig. 235.)

The application of this method has extended the bounds of chemical analysis to the planetary and stellar spaces. It can be asserted, with complete moral certainty, that the atmospheres of certain stars contain many of the metals we are acquainted with—as, for instance, hydrogen, sodium, calcium, magnesium, iron, bismuth, antimony and mercury. The colours of the stars are due to their special absorption of certain portions of the spectrum, doubtless by their gaseous envelopes.

The light of the moon shows the very same lines as the solar spectrum, showing that there is no additional absorbing atmosphere round the surface of the moon. On the other hand, the spectrum of the planet Jupiter shows unmistakable traces of additional absorption, due, no doubt, to the existence of an atmosphere.

Chemical properties of light. Light, like heat and electricity, has in some instances a combining, and in other instances, a decomposing power over substances.

908. Thus when a mixture of chlorine and hydrogen is exposed to the direct rays of the sun or any intense light, as the oxyhydrogen or lime light, a sudden combination takes place with explosion. Under diffused daylight, the gases equally combine to form the same compound, but more slowly and gradually. When kept in the dark at the same temperature they do not combine. Bunsen and Roscoe have ingeniously made the rate of combination a measure of the intensity of light for photometrical purposes, and they have thus been able to make numerous comparisons on the relative intensities of artificial lights and the light of the sun. It is a remarkable fact that the combining power resides in those rays of the spectrum which are near to the more refrangible colours, the violet and the blue. When exposed to the yellow, orange, or red rays the gases show no tendency to combine.

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* Account has of course to be taken of the dark lines due to absorption by our atmosphere. The A and B lines of Fraunhofer are now regarded as *air-lines.*

Under the influence of light, chlorine decomposes water, combines with the hydrogen, and sets free oxygen. In accordance with what has been above stated, this decomposing power is chiefly manifested by the most refrangible rays of the spectrum, blue and violet. In orange or red coloured glass no chemical action takes place. The chemical rays are therefore independent of those of light and heat. They extend beyond the most refrangible rays, and their existence may be there made evident by means of uranium glass. They may be sifted and practically separated from light by causing them to pass through a layer of deep orange (amber) or red coloured glass. These facts are brought daily into practice in the art of photography.

We have in this art an interesting illustration of the chemical power of light, or rather of certain rays which are associated with it. Freshly precipitated chloride of silver exposed to light, or to any of the coloured rays of the spectrum as low as the yellow, undergoes a remarkable chemical change. It blackens, and is reduced to the state of subchloride, or even of metallic silver, in which state it is rendered quite insoluble in certain liquids, by which the fresh chloride is readily dissolved. The white chloride kept in absolute darkness undergoes no change. On these reactions depends the production of photographic drawings on paper.

The chemical operation of light is here indicated by an evident change of colour and properties. When other compounds of silver, such as the iodide and bromide, are used in thin layers on glass or mica, there is no visible change after exposure to light, but on pouring over the exposed surface, either immediately or after the lapse of many hours (provided the films are kept in the dark), a perfect image is produced in which all the parts which have received light are darkened, while those which were in shade remain unchanged. A solvent separates the unchanged bromide, and a permanent impression is left in which light and shade are reversed. The plate, which in this state is called a negative, is subsequently employed for printing any number of positive impressions with the light and shade in their proper relations.

909. By the aid of these chemical changes and certain ingenious arrangements, light is made to record the amount of electricity in the atmosphere, the duration and force of the wind, and the relative degrees of light and darkness, with numerous other matters of scientific interest. Even the shape of a cloud, the waves of the sea in motion, and the discharge of a projectile from a gun, have been thus accurately delineated.

The chemistry of light is perhaps most strongly seen in the power which it imparts to vegetation, of fixing the carbon in the vegetable structure and liberating the oxygen from the carbonic acid of the atmosphere. A noxious ingredient is thus removed and its place is supplied by a gas, without which no animal could live. In the absence of light, the green parts of vegetables cease to eliminate oxygen. The source of fuel has been already described in the section on Heat, and it is here referred to as an illustration of the influence of light.

Light has been supposed to exert an influence on the volatility of camphor, as this substance is generally found deposited in crystals on the sides of bottles containing it, which were exposed to light. It has, however, been clearly proved that this is an effect of heat radiation and cooling, taking place more readily from the surfaces on which the camphor is deposited.

A remarkable effect of light is shown in reference to certain crystals. Santonine in a pure state is in colourless crystals. By exposure to light these crystals acquire a brilliant yellow colour. Some crystals decompose light into its complementary colours. The crystals of platino-cyanide of magnesium are of a ruby red in one aspect and an emerald green in another. These are truly dichroic. Other crystals present the shades of yellow and violet.

There are other remarkable properties possessed by light, such as the imparting electric conductivity to Selenium, as described by Dr. Siemens. These, however, require no special notice in this place.

The section on optics would not be complete in the absence of any notice of the modern wave-theory, as contrasted with the old view of light being an emanation from the sun and other self-luminous bodies. Many of the phenomena of light admit of explanation on either view, and to some, the emanation theory, which has been generally adopted throughout this section, may appear more simple and intelligible for the purposes of description.

Light was formerly regarded as an exceedingly minute material emanation from the sun or other luminous body, *shot through space with immense velocity: it is now almost universally believed to be only a mode of wave-motion in an intangible and imponderable medium, or* ETHER, *as it is called, which pervades all space, and to which ordinary visible or gross matter is more porous than sand is to water.*"

910. The material or *emission* theory of light is so very natural that we need not wonder that it was long before men would admit any other. We smell an odour from a considerable distance, doubtless by the emanation of minute particles from the odorous body,—particles far too minute to be touched or to affect any other of the senses than smell; why, then, may not light be a similar minute emission affecting only the sense of sight? The immortal Newton was the great exponent of this emission theory; and there can be no doubt that his authority weighed more in its favour than all the arguments for the rival theory did for long against it. We shall see, however, from the phenomena reviewed and described in this section, that the *wave* or *undulatory* theory of light—first propounded by the celebrated English philosopher Hooke in 1664, and, shortly after, greatly developed by the Dutch philosopher Huyghens—is the only one reconcilable with the multitude of otherwise inexplicable phenomena revealed by modern experimental research.

Side by side with the heating beams of the sun come to us his beams of life-giving light; and side by side with the motion-theory of heat, which was explained in a foregoing section, must we accept a similar motion-theory of light. That neither heat nor light can consist of material particles, has been inferred from a variety of ingenious experiments all pointing to this conclusion. The results have been especially confirmed by an experiment made by the French philosopher Fizeau with reference to the velocity of light in liquids or media denser than air. According to the Newtonian or emission theory, the velocity should be greater in the denser medium; according to the wave theory it should be less. By a beautiful experimental device Fizeau proved that the facts of the case accord with the wave theory, and not with the other, the velocity of a beam being retarded by its passage through water.

The ordinary phenomena of reflection and refraction were explained on the emission theory by Newton, with the aid of some subsidiary hypotheses as to the behaviour of luminous particles; but it is altogether unnecessary to recount these theories and explanations in the face of an array of optical phenomena disclosed since the days of Newton, which would require the multiplication of the characters ascribed to light by that illustrious philosopher, but which admit of complete explanation on the Huyghenian or wave theory.

The Ether or Wave theory of light.

911. To account for the various phenomena of light and of radiant heat, modern philosophers assume the existence of an *ether* or medium of extreme tenuity and elasticity, filling all space and pervading all ordinary matter as easily as the air passes among the trees and foliage of a forest. There is some relation between this ether and grosser matter, but it is so subtle as to have hitherto eluded philosophic hypothesis. A sufficiently intense vibration of the particles of a piece of iron causes vibrations of the ether which announce themselves to our perception as heat; and a still more intense vibration of the iron transmitted to the ether reveals itself to the eye in vibrations of the retina, which we call light (Art. 554).

From a variety of appearances it is inferred that the vibratory motion of the ether is not like that of the air in the case of sound, but rather like the waves seen in water, or the transversal waves artificially raised on a rope or elastic-string, as already described under *Acoustics* (Art. 475).

How a medium almost infinitely rarer than air can admit of these cross-vibrations, when the idea of cohesion, by which such an onward movement might be transmitted is out of the question, we cannot attempt to explain. But we are compelled to accept the conclusion from such facts as will be detailed in the following pages.

Under this hypothesis, the reflection and refraction of light admit of ready explanation. The reflection of transversal waves follows the same law as that of longitudinal ones, or as that of liquid waves; and is at once deduced from the assumption that the velocity of light is constant for the same medium.

If, on the other hand, it be assumed that within solids and liquids the density of the luminiferous ether is greater than in vacuo, owing to the interaction of gross matter and the ether, while the elasticity is also lessened by this interference of matter, it follows theoretically (and experiment justifies theory) that the light waves, on passing from one medium to another, will proceed as new waves of a different velocity, with the entering surface as their origin or source.

By simple geometrical reasoning, the law of refraction can be readily deduced from the latter assumption, and the remarkable conclusion arrived at that

The index of refraction is simply the ratio of the velocities of light in the two media.

912. Thus, when a ray of light passes from air into water, the index of refraction is, as was seen in Art. 805, $\frac{4}{3}$; in other words, the velocity of light in air bears to the velocity in water the ratio of 3 to 2.*

A further analogy between light and sound which renders the wave hypothesis of light complete, is, that the luminiferous waves are not all of one length, though they have all one common velocity. Different colours of light correspond to different wave-lengths of ether, and therefore to different numbers of vibrations of the retina per second; just as we have seen in acoustics, that different notes of the scale correspond to different wave-lengths in air and different numbers of vibrations of the tympanum per second.

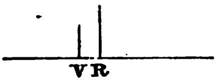

Fig. 237.

By experiments to be afterwards explained, it is calculated that the length of an average red ray of light is about $\frac{1}{39000}$th of an inch, while that of a violet one is only about $\frac{1}{58000}$th of an inch. Some idea of their extreme smallness may be formed when we say that the figure (237) represents a violet and a red wave-length magnified ten thousand times. These are the extreme limits of luminous waves, a very narrow range of vibrations when we compare it with the range of audible aërial vibrations. (See page 370.)

The number of vibrations which strike the retina per second is inconceivably great. We may express them by figures, but the mind is powerless to grasp the corresponding reality.†

The *perception of colours* is explained by the assumption that certain fibres of the retina are, so to speak, tuned to definite rates of vibration, and respond only to these, just as the wires of a piano vibrate in sympathy only with aërial vibrations of their own period. (See *Acoustics*, Art. 483.)

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* *The absolute index of refraction* is the ratio of the velocity *in vacuo* to that in the given substance, and is always greater than the index of refraction from air.

† To find the number of vibrations per second in a *red* ray, we divide the velocity of light per second, namely, 192,000 miles reduced to inches, by a red wave-length or $\frac{1}{39000}$ inch. This gives the inconceivable number of 474 millions of millions.

913. The *colours* of bodies, in like manner, would be explained by assuming that the surface-molecules or particles of bodies take up or quench certain vibrations of the ether, while others they refuse to absorb and send back to the eye; and it is by the latter that we form a judgment of the colour of the body.

A white sheet of paper reflects all the rays of light as it receives them; a blue paper absorbs all the other colours of the spectrum (or of the rainbow) except the blue; and a red paper reflects only the red rays. In the red of the spectrum, a red wafer will have its colour intensified; in the blue, it will appear almost colourless or black, because it only receives blue rays, and these it absorbs and is unable to reflect.

When light is transmitted through a coloured glass, the colouration is not due to any new property added to the beam which passes through, but is due to a quenching, sifting, or withholding of certain of the original component rays, the residue alone giving the coloured appearance to the glass.

Thus, if ordinary white light be passed first through a red glass, all the blue and green rays are quenched or sifted out of the original beam; and if the red ray be viewed through a blue glass it will appear almost black. Blue glass transmits only blue rays, not red; hence if only red fall on the blue glass no light at all will pass through.

The undulatory theory of light, in accordance with which the phenomena of the spectrum have been already explained and satisfactorily accounted for, receives further confirmation from another and entirely different class of phenomena, which will be now briefly described.

914. *Interference.*—The phenomena to which we refer are those due to the interference of luminous waves of the same intensity, whereby two lights may increase each other's effects, or may partially or entirely destroy one another, and so produce darkness out of light.* There are various natural and experimental methods whereby this interference may be produced, but the fundamental principle is the same in all, and may be easily understood.

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* These facts, as Mr. Tomlinson remarks, are totally unintelligible if light is regarded as matter; for two material particles cannot annihilate each other, as the rays of light do, and as two forces or motions can.

Suppose that, as shown in fig. 238, we have two chains, A C, B C, united to one common chain, C D, and suppose that, as explained in the section on *Acoustics*, p. 309, we have the means of sending cross or chain-waves along each towards C D (as represented by the dotted lines in the figure), then it is obvious that the disturbance of the end, C, of the chain, C D, will depend on the relative *phases* of the waves approaching from the two different quarters. That is to say, if a crest of a wave from A coincide with a hollow of a similar wave from B, then C will remain undisturbed, the one motion just extinguishing the other. If, on the other hand, the different waves coincided in direction when they arrived at C, then a wave of double amplitude would pass along the chain, C D; or, to put it in general terms, the wave-motion set up at C will be the compound or resultant of the individual wave-motions arriving from A and B.

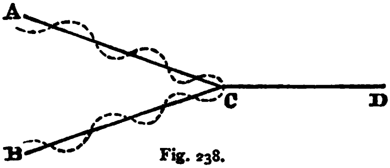

Fig. 238.

915. An exactly analogous case of interference of sonorous waves may be easily exhibited experimentally. If, with a violin-bow, we sound the fundamental note of a square metal plate fixed at the centre, we know (see Art. 542) that the adjacent quarters of the plate are vibrating in opposite phases, the nodal lines forming a central cross, as in the figure. On holding a Y-shaped tube, closed with an elastic membrane, M, over the plate, we find that sand strewn on the membrane will remain quiescent when the Y-tube is placed as in fig. 239, because the aërial pulses sent by B and C are in exactly opposite phase, and just counteract each other's effects. Whereas, if we hold the Y-tube diagonally over A and C, the sand is violently agitated.

A still simpler acoustic experiment, illustrative of interference of waves, is that of striking a tuning-fork sharply, holding it about two feet from the ear, and turning it slowly round. A position is easily found where the sound of the fork is inaudible, the pulsations from the one leg just counteracting those of the other leg.

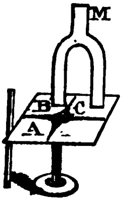

Fig. 239.

Liquid waves offer another illustration. If two waves of water arrive from different sources at the same spot at one and the same instant in such a manner that the crest of the one coincides with the hollow of the other, they will just destroy each other; whereas, if they coincide crest with crest, they will intensify each other's effects. "A magnificent example of these effects is seen in the well-known phenomena of the *spring* and *neap* tides; the tidal wave in the former case being the sum of the waves caused by the action of the sun and moon; and in the latter, their difference. The peculiarity of the tides in the port of Batsha furnishes a still more striking instance of the principle of interference. The tidal wave reaches this port by two distinct channels, which are so unequal in length that the time of arrival by one passage is exactly six hours longer than by the other. It follows from this, that when the crest of the tidal wave, or the *high water*, reaches the port by one channel, it is met by the *low water* coming through the other; and when these opposite effects are also equal, they completely neutralise each other. At particular seasons, therefore, when the morning and evening tides are equal, there is *no tide* whatever in the port of Batsha; while at other seasons there is but one *tide in the day*, whose height is the difference of the heights of the ordinary morning and evening tides." *

As a mere inference, then, of the undulatory theory, the analogy of two sounds producing silence would warrant us in arriving at the remarkable conclusion that two lights may produce darkness. But the most convincing experimental evidence has been brought to bear on this conclusion. We owe to Dr. Thomas Young the discovery of this great principle of interference, and the beautifully simple explanation which it gives of phenomena inexplicable on the old material theory of light.

916. The following experiment, due to Grimaldi, became more decisive in the hands of Dr. Young. If a beam of sun-light be admitted through two small similar holes in the shutter of a darkened room, the diverging cones of light ultimately meet and overlap; and if the light admitted be simple, that is, all of one colour or wave-length, then it is found by catching the over-lapping images on a screen, that there are a series of alternate bright and black bands. These bands disappear if one of the beams be cut off, and the dark intervals recover their brightness, proving conclusively that the darkness was due to the collision of the one set of luminous rays with the other.

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* Lloyd's 'Wave Theory of Light.'

Fig. 240 will show how the length of the ethereal waves may be calculated from this experiment. A and B represent the two openings, or sources of light, of similar wave-length; the lines drawn from each represent the diverging rays. First of all, at a point, E, exactly between A and B, two similar waves which had started together from the same source, the sun, will arrive at the same instant, and therefore in the same phase; hence their effects will conspire, and E will be a bright spot. If, again, D be a point, such that A D is shorter than B D by half a wave-length; then two waves, starting together from A and B will be in opposite phases when they meet at D; and the crest of the one will just annul the hollow of the other, or D will be a dark band: lastly, if C be situated so that A C be just one wave length less than B C, then waves leaving A and B simultaneously will coincide, crest with crest, at C, and their effects will in consequence conspire, or C will indicate a bright band. It is easy from this to see that, knowing the distance of the screen from A and B, and measuring accurately the intervals between the dark bands, we can estimate the wave-lengths corresponding to the colour of light transmitted through the apertures, A and B. If red rays are first transmitted, as by placing a glass of that colour in front of the minute openings, A and B, and then blue rays transmitted, it is found that the bands are nearer for blue rays than for red, a fact which agrees exactly with the foregoing statements as to wave-length of the colours of the spectrum (Art. 912).

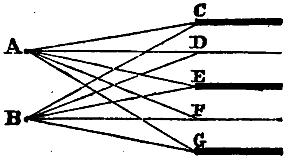

Fig. 240.

917. In this way, by accurate measurement of the distance between the openings, the distance of the screen, and the breadth of the lines, it has been estimated that the length of a wave at the extreme end of the spectrum is 266 ten millionths of an inch; and that of a wave at the extreme violet end is 167 ten millionths; or that the average length of a wave of light is 203 ten millionths of an inch; that is to say, there would be about 50,000 of them in the space of an inch. Hence heat rays are longer than chemical rays, as the former belong especially to the extreme and ultra-red part of the spectrum, while the latter belong chiefly to the violet end (Art. 908).

The famous French philosopher Fresnel devised an experiment whereby this interference could be produced without passing through apertures, which, according to the material hypothesis of light, might exert some attracting or diffracting effect on the passing beams. This consisted in allowing a beam of light from the focus of a lens to fall on two mirrors, very slightly inclined to each other, so as in fact to be almost in a straight line. To an eye viewing the reflections from the two mirrors obliquely, there will appear to be two bright lights very near together; and the interference will be apparent either when viewed directly in the eye, or when the beams are caught upon a screen, the effect being exactly the same as if the light actually proceeded from two contiguous points or openings. This is interference by *reflection.*

By means of a glass prism with a very oblique angle, a beam may be divided so as to travel in different paths; and the diverging cones of light will interfere if they meet again after having travelled unequal distances. This is interference by *refraction.*

918. There is also confirmatory evidence of the wave theory from what are known as phenomena of *diffraction.* Without going into details, the complete statement of which would involve mathematical technicalities, we may say that when a ray of light passes through a very minute opening, such for instance as a pin-hole in a sheet of tinfoil, or passes by a fine obstacle, such as a fine wire, the luminous waves bend outwards and inwards to some extent on each side of the geometrically straight path. Interference of waves in different phases thus takes place, and when the light which has passed in this way is received on a screen and carefully examined, coloured bands are seen, which are at once accounted for on the wave hypothesis of light. By drawing with a diamond, a number of minute lines very close together on a certain extent of any hard surface, we may produce coloured spectra showing a beautiful iridescence. These are owing to a similar cause. Polished steel thus treated, presents in different respects the splendid colours seen in the diamond itself. Some kinds of iridescent pearl owe their vivid colours and beauty to a minutely furrowed or striated surface, which may be seen by the microscope. This is proved by the fact that on taking an impression of the pearl on black wax, or on fusible metal, the iridescent colours are seen in the impression. There is simply a transference to the wax or metal, of the finely striated lines which produce the colours in the pearl. Fine fibres, such as the web of the spider, when a strong sunlight falls on them, present also iridescent colours.

These conditions are explicable on the principle of interference above described.

919. What are called the phenomena of *thin plates*, are also due to interference of luminous waves. The brilliant colours seen in the soap-bubble, or seen when a watch-glass or a lens, such as an eye of a pair of spectacles, is pressed on a piece of plate glass, or seen when a thin film of oil floats on clean water, are explained by the interference of the reflected luminous waves which proceed from the two surfaces of the thin transparent plate in each case. The first careful observation of these phenomena was made by Newton, and the iris-coloured rings, observed by pressing together two pieces of glass not quite flat, are generally known by the name of *Newton's Rings*. These are also seen in cracked ice, glass, or transparent crystals, and the iridescent colours of some kinds of opal are supposed to be owing to a similar cause.

Lastly, the ethereal hypothesis of light is remarkably elucidated and strengthened by a class of phenomena known as the *polarization of light*, which were at first regarded as destructive of the hypothesis; but which have now been completely reconciled with the theory.

POLARIZATION OF LIGHT.

920. If a beam of light, admitted by a hole in the shutter of a darkened room, be examined in any way, it is found to be symmetrical or of similar structure on all sides round the line or axis of transmission. If we let it fall on a plane mirror, the reflected image is equally bright and in all respects similar, on which ever side of the beam we present the mirror; the intensity depending only on the inclination of the mirror to the axis of the beam. To the naked eye this reflected beam appears to be precisely like the original one; and we should expect that, like the original, it is symmetrical on all sides round about. When, however, we try the effect of a second reflection on this reflected beam, we find that the second reflection is stronger when the second mirror is parallel to the first, than when its direction is across that of the first. The first reflected ray thus appears to have acquired *sides*, which property influences the behaviour of the beam in its subsequent course. Before explaining other methods by which this modification, or *polarization*, as it is called, of a beam is effected, we shall describe the simplest form of apparatus by which these experiments may be performed.

921. *The Polariscope.*—Two rings, C, D (fig. 241), which fit on the ends of a brass or pasteboard tube, T, carry two plane plate-glass mirrors, A and B, which are each mounted on an axle, so that they may be inclined at any angle to the axis of the tube. Fixing the tube in an upright position, and allowing diffused daylight to fall on the mirror B, inclined to the axis of the tube, we find on inclining A to the axis in a direction parallel to that of B, that the reflection of daylight from B passes through the tube and is reflected again with little diminution by A; a bright round image of the further end of the tube is seen on looking into A. If now, keeping B unchanged in position, we slowly move the ring, C, round the axis of the tube, and watch the illuminated image in A of the far end of the tube, we find that this image gets darker and darker, until when the direction of A is right across that of B, there is more or less extinction of the light, according to the angle at which the mirrors, A and B, are inclined to the axis of the tube. When the lower mirror, B, is blackened with varnish on the back, and each is inclined to the vertical or the axis of the tube at an angle of about 33°, the extinction of the light is total when the directions of the mirrors are right across each other. If we keep turning A round the axis of the tube, we find that, after making another quarter of a turn, the second reflection is as strong as at first, while with three quarters of a complete turn, there is once more total extinction.

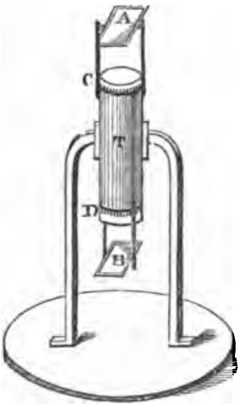

Fig. 241.

In place of B being a mirror of glass, we may use a surface of polished wood, ivory, leather, or any other non-metallic substance. The first reflector, B, is known as the *polarizer* of the light, and the second, A, as the *analyser*. Each reflecting surface has its own angle of maximum polarizing effect; and this is known as its *polarizing angle*. Sir David Brewster discovered that it bears a certain relation to the angle of refraction of the same substance; the relation being such, that when a surface is placed with respect to a beam of light at its polarizing angle, *the reflected and the refracted rays are at right angles to each other.*

The explanation of this phenomenon, which is possible under the undulatory theory alone, is that an ordinary beam of light consists of wave-motions of the ethereal medium, across the direction of the beam; that is to say, analogous to the vibrations of a sounding string. It is only on the supposition that the vibrations are *transversal* that the manifold phenomena of polarization can be accounted for; although, indeed, it is difficult to conceive of such a transverse wave-motion without the existence of a cohesive force among the ethereal particles, as there is between the particles of a vibrating string. Further, the vibrations of the ethereal particles resemble those of the parts of a sounding string in describing circular orbits round the axis of motion; each particle vibrating, not in one plane or line, but successively in all planes round the axis or direction of the beam.

Polarization of a beam of ordinary light, then, is the splitting up or resolving of the circular or helical wave-motion into two sets of plane vibrations in planes across each other.

922. We may picture a beam of common light before falling on the first reflecting plate, B, of the polariscope (fig. 241) as an exceedingly rapid helical or circular vibration of the ethereal medium, which on meeting the reflecting surface is split up into a plane wave of ethereal motion which rebounds up the tube, T, and another plane wave which passes through the plate, B, undergoing refraction, and which is quenched by the varnish on the back of the plate.

These plane or sheet waves are composed of ethereal vibrations parallel to the face of the reflecting plate, B; and, as may readily be conceived, when they fall on the plate, A, similarly disposed with B, they are simply thrown off or reflected again in their entirety, without any farther splitting up. If, however, they fall on A, disposed crossways, then they present, so to speak, their edge to the reflecting surface, and are thrown off proportionately enfeebled.

When a beam or ray of light falls on the glass plate at any other angle than that of about 56°, then the decomposition of the ethereal motion is but partial; or the ray is only *partially polarized*, and a second cross reflection in such case does not cause the same complete extinction of the beam.

A beam of light may be thus decomposed or polarized in other ways than by reflection. We may have polarization by *refraction* as well as by *reflection*. If a beam of light be made to pass through a pile of thin glass plates inclined to the direction of the beam at an angle of 56°, the polarizing angle, the components of the luminous rays which are transmitted, emerge in a state of polarization more or less perfect according to the number of plates employed.

The components of the waves perpendicular to those which emerge, are sifted out by reflection at the successive surfaces, and form the complementary polarized beam. Such a pile of plates may very conveniently be used to replace the upper or analysing plate in the polariscope (fig. 241).

Another remarkable method by which light may be thus analysed or resolved is by means of what are called double refracting crystals, of which the principal are Iceland spar and Tourmaline.

923. *Iceland spar*, or calc-spar, as it is frequently termed, is a crystalline form of carbonate of lime, which is found in considerable quantity in Iceland.

It cleaves naturally with faces shaped as in the figure, such that the angle, A B C, is about 102°, and the angle, B C D, about 78°. Fig. 242 represents a rhomb or natural block of the crystal; the line, A F, which connects the two opposite obtuse angles of the crystal is called the optic axis of the rhomb; it is equally inclined (at 45° 23′) to the three edges, which meet at A, if the rhomb is an equilateral one.

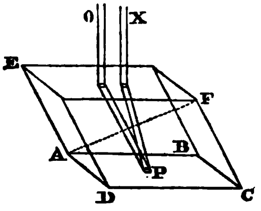

Fig. 242.

If we lay such a block of spar on a line of writing, or a page of a book, we shall see each line and letter double; if we place it over a dot, we see, not one dot apparently raised by refraction, as we should do with a similarly shaped piece of glass, but two dots, one seemingly nearer than the other; and if we turn the crystal round, we shall see the upper image remain stationary while the lower one moves round it as a centre.

On examination it is found that the higher image undergoes refraction according to the ordinary law; it is therefore called the *ordinary ray*, or image; while the other is bent or refracted according to a different or extraordinary law, and is called the *extraordinary ray* or image. When the dot is viewed through the spar in a direction parallel to its optic axis, the two images fuse into one, and the extraordinary ray becomes coincident with the ordinary one.

If we examine with the analyser of the polariscope (fig. 241) the two images, or two beams of light, thus produced by a rhomb of

Iceland spar, we find that the two rays are polarized very completely, and are complementary to each other; that is to say, when the one image is getting extinguished as we turn the analyser round, the other one is getting bright, and conversely.

If we have a pretty thick crystal, so that the two images are well separated, we may cover the face of the crystal with varnish or black paper, and leave an opening for the one image only emerging; and in this way we obtain a very valuable means of polarizing light.

The crystal known as Tourmaline has a similar property of double refraction, with this peculiarity, that the ordinary beam is more rapidly quenched than the extraordinary; and with a certain thickness of plate, the extraordinary beam alone emerges; a piece of this crystal, therefore, forms a most valuable means of polarizing light.

924. *Nicol's prism.*—Another and most convenient means of obtaining polarized light, or of examining it when polarized, is what is known as Nicol's prism. It consists of two halves of a crystal of Iceland spar, cut through the two oblique-angled corners and reunited by means of Canada balsam. Owing to the refractive index of the balsam, the ordinary image meets it at such an angle that it is reflected away to one side of the crystal, while the extraordinary ray traverses the prism uninterruptedly.

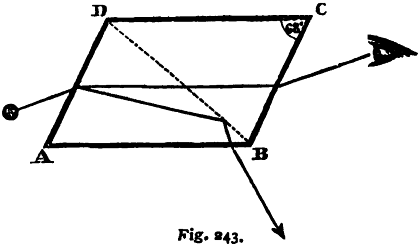

Fig. 243.

Besides the important bearing which the phenomena of polarization have upon the undulatory ethereal hypotheses of light, for the exposition of which mathematical and technical details, unsuited to this work, would require to be introduced, it has some practically useful applications.

If a piece of selenite, or of mica, be introduced between the polarizing and the analysing plates of a polariscope, it will be found that the different thicknesses of the plate are revealed by differences of the colour, the purity of the colours being sometimes of surpassing beauty. If the piece of mica or selenite be fixed while the analyser, or polarizer, is slowly turned round, the colours are all changed into their complementary tints by a quarter of a turn, while another quarter turn restores them again.

Applied to the microscope a polarizing apparatus renders distinctly and vividly visible, transparent bodies, different thicknesses corresponding to or producing different colours; and minute objects which, being transparent and colourless in ordinary light, would otherwise escape detection, are thus revealed.

925. *Polarization of Heat.*—Finally, it may be here observed that exactly similar modifications of dark *heat-rays* are produced by reflection, or by double refraction; and this furnishes one of the most convincing arguments for the theory that heat and light are mere differences of rapidity of similar ethereal undulations. By transmitting dark heat-rays through a plate of Tourmaline, and passing them next through a similar analyser, it is found that the effect of the finally emerging rays on a delicate thermometer increases and decreases, as the analyser is rotated exactly like a beam of light.

The researches of Fresnel, Forbes, Tyndall, and other investigators appear quite conclusive on this point; and to the works of these scientific leaders the reader is referred for full details of the experimental arguments in support of this theory.

> "*Light reflected from, or traversing, bodies of irregular surface and structure, or which have other peculiarities, is so modified as to produce all the phenomena of colour and varied brightness seen among natural bodies, giving them their distinctive characters and beauty.*"

926. General remarks on this part of our subject were made in the beginning of the section, in the explanations of how objects not self-luminous become visible by reflecting the light issuing from other bodies, and of the manner in which the prism separates a ray of white light into rays of the several colours which are seen in the rainbow. It was also shown that these rays, on being again mixed by convergence through another lens, became white light as before. To give an account of all that has been plausibly conjectured and written on this subject would occupy the pages of a whole volume. It would be to pass in review the various opinions which have existed respecting the nature of light, the numerous facts connected with the relation of light in its *double* or *multiple refraction*, or to the ultimate structure of material masses.

The investigations hitherto made respecting the phenomena of light, have furnished new proofs of the marvellous simplicity of nature, amidst the boundless extent and most curious variety. When men thought of the sense of touch chiefly as produced by pressure on the tips of the fingers, or elsewhere on the skin, they were far from suspecting that the sense of hearing had the near relation to it, which subsequent discoveries have proved, namely, that it is only a more soft or delicate pressure, made by undulations of the air or other substances on nerves protected within the cavity of the ear; and still less did they suspect that the sense of sight was but a yet finer touch than hearing, produced by still more subtle vibrations of a medium of light on the interior nerves of the eye. But step by step they have ascertained the facts mentioned. It is a curious resemblance that, while in sound different tones or notes depend on the *number* of vibrations in a given time, so in light do different colours seem to depend on the *number* and *extent* of the vibrations of the more subtle medium, on which the phenomena of light depend. The human imagination cannot picture to itself a simplicity more fruitful of marvellous beauty and utility than all this; yet farther, as air answers in the universe innumerable important purposes besides that of conveying sounds, so also does the medium of light minister in numerous ways, as in connection with the phenomena of heat, electricity, and magnetism.

927. The truths now positively ascertained with respect to the nature of light and vision, are among those in the wide field of scientific inquiry, which, acting on ordinary mental susceptibility, place the student in the very midst of the work of creation, awakening the most elevated thoughts of which the human mind is capable. Had there been no light in the universe, everything else in it had been, in regard to man, utterly valueless. In a word, he could not have existed. But the material of light does exist, pervading all space; and impressions made on it in one place extend rapidly over the universe, in the progressive movement called rays or *beams of light.* These beams from all parts coming to every individual may be regarded as millions of supplementary arms or feelers belonging to the individual, and making him almost everywhere present; then these members or feelers have no weight, they are never in the way, they impede nothing, and they are only known to exist when they can render service!

But, again, this miracle of LIGHT would have been totally useless had there not been an organ of corresponding delicacy to perceive it. In the *Eye* is to be considered the round window called the cornea, of perfect transparency, placed exactly in the fore part of the globe; then, behind this, is the circular curtain, the iris, with its opening, called the pupil, dilating and contracting, without consciousness of the person, to suit the varying intensity of light; and exactly behind the iris, again, is the crystalline lens, possessed of the remarkable power of bending the entering light, to form on the retina perfect pictures or images of all the objects in front, the most sensible portion of the retina being just where the images fall. Of these parts and conditions, had any one been otherwise than what it is, the whole eye had been useless, and light useless, and therefore the whole world useless to man. Then, again, we observe that there are two of these optical organs which have so entire a sympathy that they act together as *one* doubly powerful; and, finally, the sense of sight continues perfect from the birth of the individual to maturity, although during growth a continual adjustment to one another of all the delicate parts has to be maintained; and the pure liquid which distends the eyeball, if rendered turbid by any accident, is, by the actions of life, although its source be the thick red blood, gradually restored to the purest transparency. The mind which can suppose or admit that, by chance or without design, during any length of ages, one single such apparatus of vision, as above described, could have been produced, with powers of growth and reparation, must surely want the higher faculties of reason which distinguish man from the lower animals.

SECTION III.—ELECTRICITY.

ANALYSIS OF THE SECTION.

Electricity, *a subtle natural agency or affection of matter, may be excited* (i.) *by mechanical force,* (ii.) *by chemical action,* (iii.) *by heat,* (iv.) *by magnetism, or* (v.) *by the induction or neighbouring action of other similarly electrified matter. All electricity has a remarkable duality,* polarity, *or double-sidedness of character.*

(i.) Frictional Electricity, *or that excited by mechanical means, manifests itself in mechanical attractions and repulsions of light objects, and when produced in quantity by* electrical machines, *has powerful luminous, heating, physiological, and other effects. By means of the* Leyden Jar, *it may be accumulated, condensed, or stored to a high degree, so as to resemble the natural atmospheric phenomenon of* Lightning *in its effects.*

(ii.) Galvanic, *or* Voltaic Electricity, *or that which is excited by chemical action, differs from the preceding in its* intensity, *appearing not with sudden discharges, but in a continuous* current *or flow, which requires special apparatus for its detection. Its origin and its effects are alike molecular; its uses are more extensive, as its tractability is greater, than the former, travelling along metallic wires to any distance, and equally ready to exhibit its effects at any spot in the circuit. Born of chemical action, it has important chemical powers of effecting decomposition of compound substances; the special art of* electro-metallurgy *has been developed from the electrochemical effects of the galvanic battery.*

(iii.) Thermo-electricity, *or that excited by heat, is similar in character to the former; but the transformation of heat-energy into the electrical form by any apparatus yet devised has not been so complete as that of chemical energy. The chief importance of this subject centres in the* Thermopile, *a most sensitive detector of heat-changes.*

(iv.) Magnetism, *formerly ascribed to a special force, is now identified with electricity. That the magnetism of our globe, as well as of steel permanent magnets, may be due to electrical currents, is rendered highly probable by the fact that all magnetic phenomena may be imitated by electrical currents suitably disposed, and* electro-magnets *of any strength may be produced by the galvanic current circulating round soft iron. Magnets and currents have a reciprocal action, which has been reduced by Faraday to very definite laws.*

(v.) *By* Induction, *or action at a distance, electricity may be generated from* *mechanical force to almost any degree; some electricity or permanent magnetism being required as capital to start with; a large class of machines depending on this principle have been recently devised; and the effects produced have been in some instances marvellous.*

Among the manifold applications of Electricity, the Electric Telegraph holds the first place; its recent development by sea and land forming an era in the history of civilization.

Electricity, a subtle natural agency or affection of matter, may be excited, first, by friction or mechanical force.

928. When the student opens a book on Electricity, and finds in the first page a mystery thrown around this subject by the avowal that the ultimate cause or electrical agent is not yet fully known, he is apt to imagine that there is some special difficulty connected with the comprehension of a subject on which professed electricians do not agree. He may reflect, however, that the leading laws of gravitation, light, and heat were detected and turned to important uses, before any accurate ideas had been formed as to the character of the respective natural agencies.

Though we have not yet discovered the final cause of gravitation, yet the discovery of its laws by the immortal Newton, has remarkably increased men's knowledge of astronomy, and advanced many of the useful arts dependent thereupon. James Watt did not know completely the nature of heat, when he was led to the construction of the steam-engine, which has become almost synonymous with modern mechanical power. So, although men may entertain different views as to the existence of electric fluids, they have learned enough of the laws of this wonderful agent called electricity, to be able to protect their ships and buildings, as well as their lives, from the destructive thunderbolt, and to almost annihilate distance by that wonder of modern times, the electric telegraph.

We shall in the present section deal merely with the leading experimental facts of the science, which is all that the purpose of the present treatise requires.

The earliest recorded observation of an electrical phenomenon we owe to Thales, a Greek philosopher, who lived 2500 years ago. He noticed that amber (in Greek called *elektron*), when rubbed on woollen cloth, attracted small light bodies; and the name *electricity* (or *amber-action*) was subsequently given to the whole class of phenomena of which this fact noticed by Thales was but one particular instance. The science, being wholly an experimental one, slept in undeveloped embryo till 1600, when Dr. Gilbert, a physician of Queen Elizabeth, recalled attention to it in a meritorious work on magnetism and kindred phenomena.

929. *Apparatus.*—It is interesting to know how few the simple objects are which form an apparatus sufficient to exhibit the fundamental facts or truths of electricity, and that these are at hand in every ordinary dwelling-house. A person aware of this, and not choosing to make the easy experiments, would show singular disregard of important natural knowledge. The requisites are—

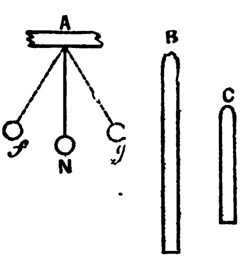

Fig. 244.

1. A silk handkerchief, or a piece of woollen cloth.
2. A piece of glass tube, as B (fig. 244), or a long narrow phial. Some wine-glasses, G, H.
3. Small round pieces of cork or balls of elder-pith, as N, hanging from any support by threads of white silk.
4. A stick of sealing-wax, or of shell-lac, C.
5. A common fire-poker, or any rod of metal, D.

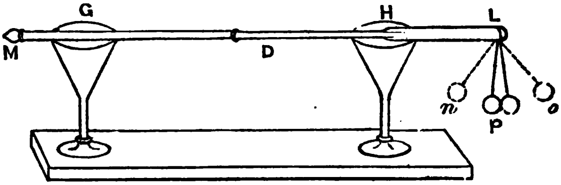

Fig. 245.

930. *Experiments.*—(*a.*) If a glass tube, B, or the bottom of a wine-glass, well dried and warmed, be rubbed briskly with a silk handkerchief also made dry and warm, and if it be then held towards the cork ball, N (fig. 244), hanging from the support, A, by a thread of white sewing silk, the ball will be drawn or attracted from the position, A N, to that of A *g*, nearer to the glass, and there it will remain while the position and electrical state of the glass continue. If the glass be moved about, the ball will move to follow it.

(*b.*) If then the electrified glass and ball are allowed to touch each other, the ball receiving part of the electricity would instantly dart away or be repelled by the glass; and if the glass be moved towards it from any side, it will elude the approach, like a living thing terrified.

(*c.*) After the contact of the glass and ball, the ball will have acquired the power of attracting any other light thing placed near it, as a second ball like itself, and if these be allowed to touch, they will instantly repel mutually, as the glass and ball did in the last experiment.

(*d.*) A glass tube being a *non-conductor* of electricity, if held by one end, loses its charge only slowly, and chiefly to the air; but if a hand be passed along its surface, the hand, being a *conductor*, carries away the electricity, and the natural or normal state of the tube is restored. So an electrified cork ball, which attracts and is attracted by things around, if allowed to touch a finger, loses its electricity and comes to rest in the natural position of the pendulum.

(*e.*) If, instead of one ball hanging from the support, there are two, and in contact as at the point L, on touching them with the electrified glass, they dart asunder, and if the glass be placed between them, they separate still further.

(*f.*) If a metallic rod, D, as a common fire-poker or a length of thick wire (both being conductors), has attached to it, at one end, L, two pith-balls hanging by fine wire or linen thread, and if the rod be insulated by being supported on two wine-glasses, G and H, as shown above, and if then the end of the rod, M, be touched by the excited glass tube, the two balls at the end, L, will instantly repel each other as if the glass had touched them directly, showing that the metallic rod gives instant passage to the electricity from the glass to the balls. The rod or wire might be of great length, and still the effect would be produced.

(*g.*) If the electricity be strongly excited on a large glass tube in the dark, the surface is often slightly luminous, and minute sparks are seen to pass from the glass to knuckles held near, and a slight crackling noise is heard, showing that all our senses can perceive excited electricity

(*h.*) The set of experiments described above may be performed more feebly by using the silk with which the glass had been rubbed, as the electrifier, instead of the glass itself, but with this singular difference, that the bodies which are attracted by the glass are repelled by the silk, and *vice versâ.* One of the rubbing bodies seems to gain that which the other loses.

(*i.*) There is the same remarkable opposition, if, instead of using glass and silk to evolve the electricity, a stick of sealing-wax and silk or woollen cloth are employed. The electricity from the sealing-wax is of the contrary nature to that from the glass, and of the same nature as that from the silk which has rubbed the glass.

931. The results of these and such like experiments may be summarized as follows :—

1. If we rub with a dry silk or flannel cloth any of these substances — sealing-wax, shellac, glass, sulphur, ebonite, vulcanite, writing-paper or catskin,—we develope in them an electric or attractive power which readily manifests its effects on light bodies such as pith-balls, chaff, or paper.

2. There are two distinct classes or kinds of the electric condition, which may be readily exhibited in this way. A stand, A B, is made of a glass rod or tube, bent as in the figure, with the heat of a gas or spirit flame; and a paper stirrup, C, is hung from the stand by a white silk thread. Having provided another similar insulating stand, with two small sticks of sealing-wax, and two rods of glass, we find that, on rubbing the ends of two sticks of wax, and placing them in the stirrups and bringing them near, they mutually repel; also, if we substitute for these the two glass rods, after rubbing them briskly, they similarly repel each other; but if into one stirrup we put a rubbed stick of wax and into the other a rubbed stick of glass, they attract. Moreover, all substances capable of exhibiting these electric actions, either repel or attract the rubbed stick of wax, while they attract or repel the rubbed stick of glass.* These actions are in virtue of their electricities; hence

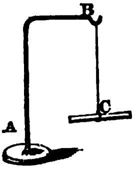

Fig. 246.

The fundamental law of electric action is—Like electricities repel each other (as we shall see like poles of a magnet repel), while unlike electricities attract each other.

Since all electricity generated by friction is thus either like that of the glass or of the wax; the names *vitreous* and *resinous* used to be given to distinguish those two classes. The names *positive electricity* and *negative electricity* are the modern and less objectionable terms employed.

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* These properties may be exemplified in another way. Place a portion of sheet gutta-percha, about eight inches long and two wide, on a folded silk handkerchief or on a layer of dry flannel. Gently rub it in one direction by the flat portion of the thumb. It soon becomes so electrical that it will be strongly attracted by the hand or anything brought near to it. If brought

932. If we hang a small pith-ball instead of the paper stirrup at the end of our silk string (fig. 246), this forms a ready and sensitive test of the presence or absence of the electric power.

By means of it we discover that when we rub a stick of sealing-wax with a silk handkerchief, it attracts the ball and then repels it; but the pith, electrified and repelled by the wax, will be attracted by the silk rubber. Thus the two kinds of electricity are always simultaneously produced; and this countenances the hypothesis of *two electric fluids*, which, like an acid and an alkali, neutralize each other when present in equal quantity, but which have a strong attraction or affinity when separated. The generation of electricity is but the separation of these two fluids, and *friction* is, as we shall see, only one of many means whereby this separation can be effected.*

The other, and *single-fluid theory*, of electrical action regards the natural or unelectrified state of a body as merely a body having the same amount of the electric fluid as the surrounding surface of the earth; while electrification is, so to speak, the disturbance of this electrical equilibrium, a body being positively electrical when there is an accumulation or heaping up of the electric fluid on it, and negatively electrical when there is a withdrawal of the normal quantity.

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near glass (a mirror) it will fly to it and adhere to it for many hours. If two layers of gutta-percha are thus separately treated and brought near to each other, they show all the properties of repulsion above described.

The thin transparent membrane left by the evaporation of collodion (gun-cotton dissolved in ether) is one of the most electrical substances in nature. The slightest friction, even through a layer of paper, renders it so powerfully electrical that it can scarcely be removed from the paper without being torn.

* Heat produces, or is converted into, electricity. Thus, if a flat iron, moderately heated, is passed over albumenized paper, placed on a surface of dry wood or silk, it becomes strongly electrical. Paper photographs thus ironed are powerfully attracted to the hands of the operator, and the sensation of a sort of aura, owing to the passage of electricity, is perceived. Owing to the well-known law of repulsion, these slips of paper or thin drawings strongly repel each other; but are attracted to other drawings which have not been in contact with the flat iron.

The laws of the science are but little influenced whichever theory we choose to adopt.

933. There is a remarkable difference among substances in their power of conducting electricity. When a glass rod, or stick of wax, is rubbed it is electrified only at the spot where it was rubbed. If, however, we communicate its electricity to a metal rod, such as our poker (fig. 245), the manifestation appears at every part of the conductor at the same instant. Hence is explained the fact, that a metal rod treated like the glass rod shows no appearance of electricity. As fast as we produce it, the effect spreads over the whole rod and thence through the body to the earth, the universal recipient and reservoir of all our actions.

The following is a classified list of bodies, according to their power of transmitting electricity :—

Conductors.	*Insulators.*
Metals.	Oils.
Charcoal.	Chalk, Lime, Marble.
Acids.	Porcelain, Wood.
Saline solutions.	Leather, Parchment.
Liquids generally.	Dry Paper, Wool.
Living Vegetables and Animals.	Silk, Glass, Gems.
	India-rubber, Ebonite.
Flame.	Amber, Wax, Shellac.
Moist Earth.	Resins generally.
Ice.	Dry Air and Gases.

934. *The Electrical Machine.*—When persons had become familiar with the simple experiments already described, they naturally concluded that with larger apparatus of a similar nature, the phenomena might be exhibited on a grander scale, and that probably new facts of importance would be discovered. The result of many devices and trials was the construction of what is called the frictional electric machine now to be described.

The essentials of any electrical machine are three :—the glass, or non-conductor, to be rubbed ; the rubber ; and the conducting reservoir to receive the electricity. In lieu of the simple tube in our elementary experiment, may be substituted a large glass cylinder as A B (fig. 247), about twenty inches long and half as wide, to be turned, like a grindstone or barrel-organ, by a winch-handle, W. It is insulated by being supported on glass pillars, H and I.

Secondly, instead of the loose handkerchief for rubbing, there is used a flap or breadth of silk cloth laid on the upper part of the cylinder, of which flap half is here seen, C D E F, the other half being behind, with its horizontal edge or border fixed on a cross piece of wood, also supported on a glass pillar, K. This cross piece has a soft covering, rendering it a cushion which bears gently against the cylinder, and becomes the solid part of the rubber. Thirdly, instead of the cork or pith balls to receive the electricity, there is the large metal cylinder with rounded ends, L M, also having a glass support. This cylinder is called the *prime conductor*, and when in its place, its extremity, L, with metallic points projecting to receive the electricity, is brought close to the loose border of the silk, E F.

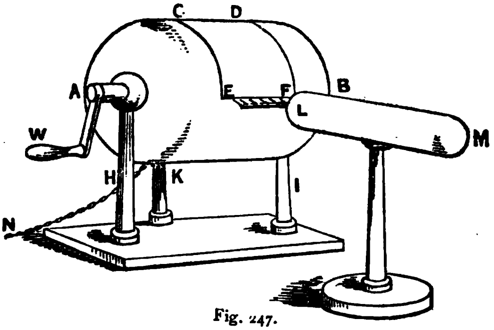

Fig. 247.

As the cylinder is turned, electricity is evolved by the rubbing silk on the glass surface, and is carried forward to be delivered through the metallic points to the prime conductor, L M, where the silk terminates.* There is a metal chain connecting the cushion of the rubber with the ground at N ; and by this means the rubber is kept at the same electrical level, as it is called, with the earth, while the electrical agitation, excitement, or affection is heightened, or so to speak, heaped up on the prime conductor.

935. The intensity or degree of this electrical accumulation on the prime conductor may be ascertained roughly by placing on some part of it, as at M, a small *pendulum electrometer*, consisting of a pith-ball, *b*, hanging by a slender arm, *a b*, from the top of an upright stalk, *a c* (fig. 248). The greater the electrical accumulation, the farther is the pith-ball repelled from the stalk.

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* This is a hollow cylinder, as electricity is always accumulated over the surface of metals. See Art. 937.

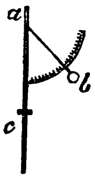

Fig. 248.

A similar electrometer placed on the rubber cushion behind, if the earth-chain, N, were removed, would show the degree of *complementary* electrical affections excited in both the prime conductor and the rubber, and would show the value of the earth-chain in allowing the accumulation of positive electricity on the prime conductor; for if the earth-chain be removed the strength of electricity that can be accumulated is comparatively insignificant.

936. The *Plate machine* is another form of electrical machine in common use. It consists simply of a circular disc of plate-glass, turning on its axle, instead of the bottle or cylinder shown above; and the supports, rubbing silk, and conductor are formed and arranged to suit it. The advantages of the plate arrangement are that both sides of the glass are made available for friction, and the labour of turning is less than with the cylinder for the same extent of surface. On the other hand, the glass plate is very liable to crack when placed near the fire for drying purposes. An exceedingly good and suitable substitute for glass is *vulcanite*, or hard india-rubber (*caoutchouc durci*, as the French term it), a compound of india-rubber and sulphur.

When a large electrical machine, like any one of those above described, is employed, instead of the diminutive apparatus sketched in Art. 929, there are the following differences:—The faint luminosity on the simple tube is converted into vivid sparks constituting almost a cascade of fire passing from the loose end of the rubbing silk to the prime conductor, and at short intervals a decided flash with loud crack darts from the conductor to any object placed near it. If a bystander approach his hand he receives the spark or flash with a painful prick and even with momentary numbness along the arm. A person insulated by standing on a stool with glass feet, if he touch the conductor, becomes so strongly electrified as to give out sparks from the fingers to a person wishing to shake hands with him. These sparks are strong enough to light a gas lamp or to explode a fulminating powder.

When the equable distribution of electricity in bodies is disturbed by friction or otherwise, causing redundancy in one body and deficiency in another, the self-repulsion, where there is redundancy, causes the electricity to pass instantly from where it is in excess, through any conducting substance which offers, either to the earth, which is the general reservoir, or still more readily to a body in a negative state; and where no conducting medium is very near, the fluid may force its way or burst through a short length or thickness of a non-conducting substance, such as air, heating it by the violence of its passage.

937. By the use of the large machines other important facts were soon discovered. Thus, owing to the self-repellent nature of electricity, when it is thrown in excess on any conducting body, it diffuses itself not through the whole mass, but over the surface only. If the body be a sphere or ball, A (fig. 249), suspended by a silken cord and highly electrified, and if there be two metallic cups, B and C, which exactly cover or fit the sphere, A, if the cups, having handles of glass, be applied closely to the ball, and then removed, the whole charge of electricity is found to have passed to the cups, leaving the ball in a perfectly neutral or normal state.

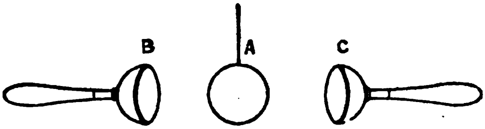

Fig. 249.

Faraday, with his beautiful experimental simplicity, showed the same fact by means of a conical muslin net attached to a metallic ring, A B (fig. 250), and capable of being turned inside out by means of a silk string, E D, attached to the apex, C, of the cone. On electrifying strongly, he found that there were no electric symptoms inside the net, only outside; but when the net was turned outside in, the electricity could not be turned outside in also, for it still remained outside.

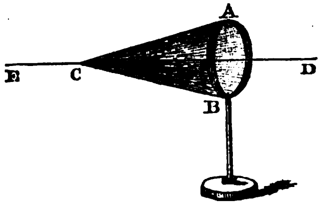

Fig. 250.

938. Owing to the same self-repellent nature of the electricity, when a charge is thrown on any body, it does not spread or distribute itself uniformly over the body unless the form be that of a perfect sphere or ball as *a* (fig. 251). If the body be oblong, as *b*, the repulsion of the fluid in the central parts increases the density of it towards the ends. Then, if one end be smaller than the other, as in *c*, the density is greatest at the small end. If the extremity be a point as in *d*, the density becomes there so great that the electricity is forced into the air, and gradually escapes. The flame of a candle held near an electrified point appears to be blown away from it; this is the result of the outward rush of air-particles by electrification and repulsion at the point. For the same reason that positively electrified points quickly dissipate positive electricity, so do points in a negatively electrified body readily receive it. This is seen in the action of the points placed between the receiver or conductor of an electrical machine and the cylinder. The fact is turned to account by giving to common lightning-rods sharp points directed to the sky.

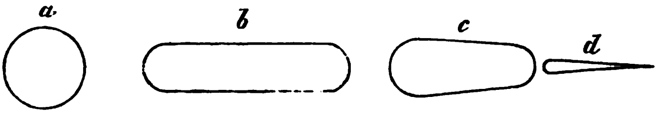

Fig. 251.

939. *Electrical Induction.*—The action of an electrified body upon a non-electrified conductor near it, but not in contact, is very curious, and of great importance. Its study reveals the nature of electric action generally, and forms one of the first analogies between the attractions and repulsions of electricity and those of magnetism. This action at a distance is known as *induction*, and we now proceed to explain it.

Let *a b* (fig. 252) be a conductor insulated by glass supports, and having pairs of pith-balls hanging by linen threads or fine wires from the ends, *a b*, and the middle, *c*. When not electrified, all the balls hang in contact, but if a positively electrified metal sphere, *e*, be brought near to the conductor, yet not touching it, the two balls at *a* and *b* will instantly repel and fly apart as here shown by the dotted lines, those at *b* becoming negatively electrified, owing to the natural electricity of the conductor being driven towards the end, *a*, by the repulsion of the positive electricity in the ball, *e*, and those at *a* becoming positively electrified, because the natural electricity of the end, *b*, of the cylinder is driven to *a*, making a positive charge there. No effect is produced on balls at *c*, half way between the ends, because the quantity of electricity there remains the same. If the sphere, *e*, be withdrawn, all the repulsions described immediately cease.

If, during the last experiment, while the electrified body, *e*, is held near the conductor, *a b*, causing the disturbance of the electric pendulums above described, a finger be applied for a moment to the conductor at *a*, allowing the positive electricity accumulated there to escape towards the earth, the pendulums immediately collapse. If after this the electrified ball, *e*, be taken away, the piths, *a* and *b*, immediately diverge again, and the conductor remains permanently charged in the negative electrical state. If then a finger approach the conductor it gives a spark, which restores what was taken away when the charged ball was present. This operation may be repeated many times by bringing back the same charged ball, *e*, at every repetition. If the ball could be long preserved without losing its positive charge, it would give the power of producing at will for the whole time sparks of considerable force. This principle is referred to in the description of the *electrophorus* in Art. 942, the nature of which it explains.

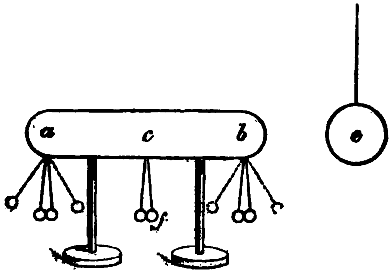

Fig. 252.

It is a remarkable fact, that if a pane of glass be held between the ball, *e*, and the conductor, *a b*, or in the experiments described afterwards, between the glass tube or sealing-wax and the pith-balls, the attractions and repulsions still occur as if the pane were not there. The glass, therefore, although, as a non-conductor, it prevents altogether the passage through it of electricity itself, does not lessen that influence at a distance, which is called its *power of induction*.

940. *The Electroscope.*—A very sensitive electroscope, or detector of electricity, which acts by induction, is represented in fig, 253, and may be described here. Its essential parts are the brass rod, *a b*, with a knob at the top, and two strips of gold leaf hanging from the bottom, *b*, within a glass shade to prevent disturbance from air-currents. When there is no free electricity near, the leaves hang in contact, but with the slightest electrical charge, whether positive or negative, they stand asunder towards *c d*, and more or less, according to the strength of the charge. If any electrified body approach the ball, *a*, it acts by induction and throws the ball, *a*, into the contrary electric state to its own, as explained in Art. 939, and the induced charge in *a*, produces the opposite charge in the leaves below, which are therefore mutually repelled. A piece of glass tube rubbed with silk, if made to approach *a*, causes the leaves to separate, because of its positive electricity, and when it is removed, the leaves collapse; but if the glass be allowed to touch the ball, the separation of the leaves remains after the tube is taken away, for a positive charge has been given. A stick of excited sealing-wax then brought near, causes, first, collapse of the leaves, but if allowed to touch, produces continued separation by negative electricity. The kind of electricity with which the leaves may be charged, is thus discovered at once by approaching to the ball either a rod of glass or one of sealing-wax, excited by rubbing.

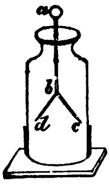

Fig. 253.

941. Faraday made some experiments to ascertain the part played by the air in this phenomenon of electric induction; and he came to the conclusion that the inductive action is not, like that of gravity, really an action at a distance, but that each little molecule of air is charged negatively on the side next the positively charged inducing body, and positively on the opposite face. These air particles are consequently the vehicle of the electric action, instead of playing the merely passive part which they were supposed to do according to former theories. Faraday strengthened this hypothesis by further experiments on the inductive power of other intervening insulators, such as glass, wax, resin, sulphur, and shellac; and he found remarkable differences. Glass, for instance, he found to operate almost *twice* as powerfully as air in inducing electricity between a charged and a neutral conductor: while shellac and sulphur are even more favourable to induction than glass.

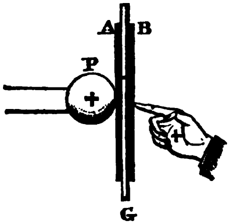

Fig. 254.

The *inductive*, or *dielectric*, power of a *non-conducting* medium such as glass, or resin, or vulcanite, may be very well shown in the following way:—If a source of positive electricity, such as the prime conductor, P (fig. 254), of a machine, be applied to one side of a pane of plate glass, G, each side of which is coated with a sheet of tin-foil, or other metal conductor, it will induce through the medium of the glass a negative charge on the face of the conductor, A, next to P, while the positive accumulation is on the side of B farthest from P. If, as in the case already described, the outside face of B be touched by the finger, its positive charge passes to the earth, and B, on the removal of both the hand and the prime conductor, remains permanently charged with negative electricity. On touching the plate, A, with one hand, and B with the other, we should then get a more or less powerful shock. Indeed this *Franklin's pane*, as it is termed, from the name of the illustrious philosopher who first used it, becomes a very powerful means of cumulating or storing electricity.

That the glass has most to do with the electric capacity which this arrangement possesses, is proved by the fact that if both metallic coatings be made movable they may be removed, discharged separately, put back into position, and give a spark almost as powerful as before.

942. The *Electrophorus* (electric carrier), as it is termed, is a simple arrangement on an analogous principle, by which a charge of electricity can be preserved for a long time (in dry weather for weeks or even months) in a condition which allows other small charges to be produced by it inductively.

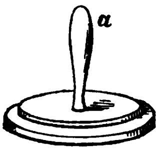

Fig. 255.

It is formed in this way:—A mixture of shellac, resin, and turpentine, melted together, is poured into a mould of metal of the breadth of a dinner-plate, so as to form, when cooled, a solid cake about half an inch thick. Upon the surface of this cake, resting on a table, is placed on a metallic disc or plate, somewhat smaller than the cake, and having a glass handle, *a* (fig. 255), by which it can be lifted away from the cake. To prepare for use, the cake is struck briskly a few times with a catskin, or a piece of warm flannel, and is thereby rendered highly electric negatively. The metal plate, being then placed upon it, has positive electricity induced on the face next the cake, and negative on the farther face. If now with the finger we touch the upper surface, the negative on the upper surface escapes to the earth, while the positive remains on the plate; and on lifting the plate with its charge away from the influence of the cake, we obtain a spark of greater or less intensity; and by simply repeating the operation of placing the cover on the cake, touching the cover, and then lifting it, we may obtain any number of such sparks. The spark may be strong enough to light a gas jet, and to serve many useful electrical purposes; and the operation may be repeated any number of times for days or even months, without any necessity for renewing the friction with the catskin.

A cake of vulcanite or ebonite, it may be remarked, forms a very convenient substitute for the more brittle compound resinous cake above described.

943. *Rotatory Electrophorus.*—Within recent years there have been devised various methods of employing the continuous electrophorus principle for the production of electricity in quantity, and without the labour of touching with the finger and lifting the cover for each little electrical charge.

A form of revolving electrophorus, the invention of M. Bertsch, is shown in fig. 256, where the insulating supports are omitted in order to render the principle of its action more clear. It consists of a vulcanite disc, V, about 20 inches in diameter, which can be rapidly rotated by an arrangement of multiplying wheels, H. A sector of vulcanite, I, acts as the *inductor*, or inducing source of electricity. Opposite to I, and on the other side of the vulcanite plate, V, is a metallic comb or rake, C, which communicates with the conductor, N; at the extremity of the same diameter of the plate is a second metal comb, C′, which communicates with the other conductor, P. If we excite the inducing piece, I, by striking with a catskin or otherwise, and bring it near to the

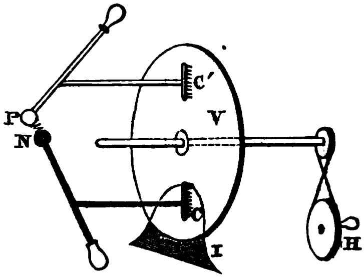

Fig. 256.

plate, while we rapidly rotate the latter, it is found that a series of brilliant electrical sparks pass between P and N, the two poles of the machine; and in dry frosty weather we may thus have an indefinite source of electricity by merely rotating the handle, H.

The theory of the electric action is rather complicated, but it may be roughly given in this way:—The negative electricity in I induces positive on the face of the plate, V, next itself, and negative on the opposite face next the comb. The latter combines readily with the positive in the conducting system, N C, owing to the effect of the pointed teeth of C. (See Art. 938.) Thus N C remains negatively charged; and the part of the vulcanite disc opposite to it positively charged. As the disc rotates, the part of the plate positively charged comes opposite to the comb-rake, C′, of the conducting system, P C′, and in the same way as before discharges the negative electricity of this system, charging P positively; and passing on in the neutral condition as at first towards the inductor, I, where the same effects recur. With a rapid rotation of the disc, and a dry atmosphere, there may in this way be accumulated a sufficient quantity and strength of opposite electrical charges in the two poles, P and N, of the machine, to dart through the distance of a few inches. The whole forms an exceedingly simple and elegant substitute for the old cylinder or plate machines.

944. *Holtz's Induction Machine.*—Somewhat analogous in principle to the machine just described is that invented by M. Holtz of Berlin, in 1865, which has become quite a favourite with electricians. The figure gives a simple plan of the machine; the omitted details of insulation will be readily understood. It consists of two glass plates, A and B (fig. 257), of which the former can be rapidly rotated by the multiplying wheels, W, W′; while B B remains stationary. The centre of the fixed wheel is pierced with an opening to allow the axle of A to pass through; and two other openings or windows are made in a horizontal diameter of B B, opposite to I, I′, which are pieces of paper or tinfoil pasted on the disc, and having tongues projecting into the windows. On the other side of the rotating disc, A, are

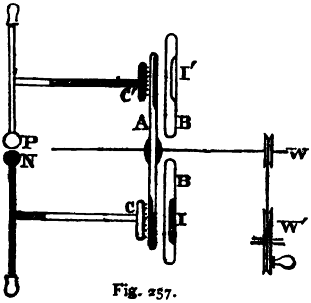

Fig. 257.

metallic combs or rakes, C, C′, which communicate with the conducting systems, N and P. The action of the machine may be summarily explained as follows :—One inductor, I, is charged negatively by contact with a piece of excited vulcanite ; I induces positive electricity on the face of A next to it, and negative on the opposite face ; the latter discharges the positive of the conducting system, N C, and leaves the latter negatively charged. The wheel turns round towards C′, charged positively, and electrifies I′ also positively, while, at the same instant, it draws the negative electricity of the conducting system, P C′, through the teeth of the comb, C′, rendering P positively electrical. Thus the sector of the plate which left C with positive, leaves C′ with negative electricity, and returning to C so charged, at once heightens the negative charge of the inductor, I, and of the pole, N. The accumulation of opposite electricities in N and P, as well as in I and I′, in this way proceeds at a compound rate ; and a torrent of very powerful sparks will in course pass between the two poles of the machine.

In dry, frosty weather this apparatus works most admirably, and is infinitely superior to the older machines, only an exceeding sensitiveness to moisture renders it a much more troublesome servant.

Many other electrical accumulators have been constructed on the same principle as those above mentioned, by Sir W. Thomson, Mr. Varley, and others ; but the above will serve as types of the whole class.

945. *The Leyden Jar.*—The inductive condensation or cumulation of electricity by means of what is now known as the Leyden jar, was discovered by accident in the year 1748, to the great surprise of those who witnessed it, and of the scientific world generally.

An experimenter at Leyden, in Holland, with a view to ascertain the effect of electrifying water, placed in a phial containing water a short brass rod, and then held the end of the rod in contact with the charged conductor of an electrical machine. Having charged the water fully, as he supposed, he removed it from the contact, and then applying the other hand to withdraw the wire from the phial, he instantly received a violent shock through his arms and body, which caused him to drop the phial, and himself to sink benumbed to the floor. He believed that he had narrowly escaped death ; and he afterwards said that he would not take another such shock if the empire of Germany were offered as the bribe.

It was soon discovered, however, that the charge was not in the water, but connected with the surfaces of the glass, the water serving merely as the conducting medium which joined together in action the several parts of the internal surface of the non-conducting glass; for the same effect was produced by substituting for the water a leaf of tinfoil, which could similarly cover the surface of the glass. And if both the internal and external surfaces of a bottle or jar were covered with tinfoil, to within a short distance of the top, the jar could then receive a very powerful charge indeed. The adjoining figure (258) shows the common form of jar so covered, and known as the *Leyden Jar.* A brass rod with a knob at its top passes through a wooden stopper into the jar, and has a piece of chain hanging from its bottom in contact with the metallic lining, to establish communication.

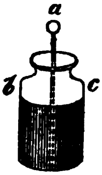

Fig. 258.

In order to charge such a jar we bring the knob, *a*, into communication with some source of electricity, such as the prime conductor of any of the electric machines already described; while we connect the outside coating with the earth either by holding the jar in the hand, or setting it on a table and fastening a long chain round it. The mode of action may be conceived to be this. While the inner coating of the jar is charged with positive electricity it induces negative on the face of the outside coating next itself, and positive on the outer face; and unless the latter be allowed to escape, a limit to the inductive action of the inner coating is shortly reached.

946. This relation between the electrical states of the two sides of a moderate thickness of glass, or other non-conductor of electricity, is shown by the fact that if a Leyden jar resting on a support of glass be charged by distinct sparks from a prime conductor—as the jar, B, from the conductor, A (fig. 259)—then for every spark

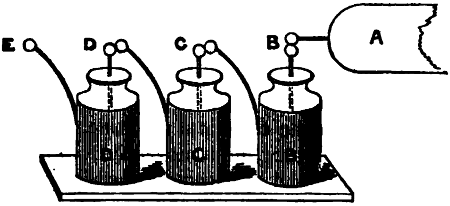

Fig. 259.

which enters it a corresponding spark is driven from the outside to any conductor placed near, as C, for instance, which is another jar, and if a row or series of such insulated jars stand as here represented, the charging of the first one, B, will charge all the others to the same degree ; and if the outer coating of the last be connected with the earth, E, then the whole three jars may be simultaneously charged very strongly.

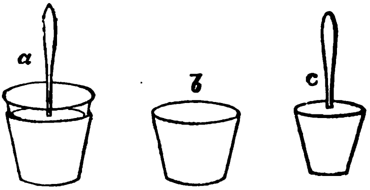

Fig. 260.

It is, however, the glass that is the chief seat of the electrical accumulation. For if a common glass tumbler, *a* (fig. 260), be set into a metallic vessel, *b*, which exactly fits and covers the lower part of its external surface, and if it then receive into itself a smaller tin vessel, *c*, with a handle of glass which closely fits the internal surface, the combination of the three, *a*, may be strongly electrified and discharged like a coated Leyden jar ; but if, after being electrified, the smaller tin cover is lifted out by its glass handle, and the external tin cover is allowed to fall off, these tins are found to be in a natural state, and the whole electrical charge remains on the surfaces of the glass. The charge so left can be made to produce its usual effects by replacing the tins.

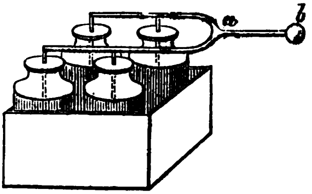

Fig. 261.

947. *The Electric Battery.*—The discovery of the nature of the Leyden jar gave an increased power of accumulating electricity, which changed the character of electrical proceedings. By connecting the interiors of many jars, and also the exteriors, to cause them to act like one larger jar, as represented in fig. 261, effects may be produced similar to those of the natural lightning of a thunder-storm. This combination is possible to any extent, and is called an *Electric Battery.*

948. The adjoining cut represents what is called a *General Discharger*, by means of which an experimenter can, without danger to himself, send the charge of the most powerful battery through any substance exposed in its way. There are two branches, *a c* and *b c* (fig. 262), hinged together like the legs of a pair of tongs, with knobs at the ends, and with a glass handle, *d*. If one knob be placed in contact with a conductor which communicates with either the external or internal surface of a battery, and if the other knob is then made to touch some conducting substance which leads to the other surface, the discharge instantly takes place, and electrical equilibrium is restored.

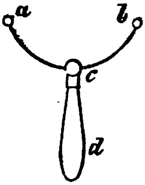

Fig. 262.

It remains to enumerate some of the many experiments, both instructive and interesting, which may be performed with the apparatus we have described. These are, however, so numerous, that in a work like the present we shall attempt to give only typical experiments, leaving fuller catalogues and minutiæ to special treatises on this subject, which, within so very short space of time, has grown from infantile to giant proportions.

949. In the first place, the *mechanical effects* of attraction and repulsion are exhibited by the following experiments :—

A common glass tumbler, strongly electrified by the prime conductor of a machine, and inverted over a few pith balls on a table, causes an amusing dance of the balls between the tumbler and the table. The dance will continue till they carry all the electricity of the tumbler to the earth.

Pith figures may be made to dance by the unseen power of electricity between a metal plate, hung by a chain from the prime conductor of an electric machine, and a similar plate placed beneath, in connection with the earth.

A small paper kite, tied by a string to the prime conductor of a machine, will get electrified and then keep floating, by electric repulsion, round the knob.

If a few pieces of paper, or pith balls, or wafers, be laid on the lid of an electrophorus, these will, on our lifting the cover, get electrified and repelled, floating away in a curious manner.

If an excited stick of sealing-wax be brought near to a fine jet of water, the electrification of the water by induction causes the jet to keep together longer than it otherwise would.

A Leyden jar discharged against a plate of resin or vulcanite over which some fine lycopodium powder is strewed, causes a curious disposition of the powder, which is very different in type according as the charge communicated is positive or negative. These are known as *Lichtenberg's Figures.*

If a person stand on an insulating stool, such as a stool with glass legs, with one hand on the prime conductor of a machine in good working order, he becomes electrified, and the hairs of his head stand on end in consequence of their mutual repulsion. A person standing near, may draw sparks from his electrified neighbour; and the latter, by simply putting his finger or knuckle to a gas-jet, is able to inflame it.

If a wire ending in a fine point be fixed on the prime conductor, the electrification and consequent repulsion of the air-particles by the point is felt on the hand or face like wind blowing from the point. This electric wind will suffice to drive a small wheel or orrery with paper vanes.

If a small tin pail have holes pierced in its bottom, so fine that water poured into it will issue only drop by drop, the electrification of the water will cause it to issue in fine streamlets.

950. Secondly, the heating and luminous effects of the electric discharge may be shown by a variety of pleasing experiments.

The bright spark seen when the knuckle or a conductor is presented to an electrified body, is due either to the incandescence of minute particles of the conductor, or to combustion of the atmospheric gases.

This spark passes into a diffused light when the discharge takes place in rarefied air, as, for instance, between a platinum wire sealed in the close end of a barometer-tube and a mercurial column. Spectroscopic examination of this light shows it to be due to the incandescence of the aërial traces remaining in the tube, and of the vapour of mercury. In a perfect vacuum, however, it is found that no discharge takes place, showing that electricity must always have a material means of conduction. The spectrum of the *Aurora borealis* shows distinctly the lines due to the incandescence of nitrogen, proving that this phenomenon is due to diffuse electric discharges in the higher and rarefied regions of the atmosphere.

When the electric spark is examined in the dark, it exhibits the following peculiarities:—When short and strong, it is a straight stream of fire between the two conductors; when the spark passes over a considerable distance, it is crooked and branching, like the tributaries of a stream; the divergence from the straight path being in all probability due to the interference of dust particles floating in the air.

When the machine is worked in the dark, and in good condition, spontaneous discharges into the air occur; these take the form of a *brush* ordinarily; and if a conductor be presented to this brush, the streams of light converge upon it; if, however, the conductor be fitted with a fine point, no brush appears; the electricity passes silently into the air, and the point is crowned with a simple spot or *glow* of light. The light of the electric discharge also exhibits differences of colour, according to the nature of the metals between which it takes place. Holtz's machine is particularly fitted to show these luminous effects of the discharge.

If a Leyden jar or battery, strongly charged, be discharged through a leaf of gold, silver, tin, or copper, or a fine iron wire, the heat of the discharge is sufficient to burn up the metals, or even dissipate them into vapour. The spark of a small jar, or even of an electrophorus, is sufficient to inflame a mixture of explosive gases, such as oxygen and hydrogen, or common coal-gas and air, and is employed constantly in chemical laboratories for this purpose.

Toy pistols and toy cannon are constructed on this principle; they are filled with a mixture of common coal-gas and air, and the mouth plugged air-tight with a cork or wooden ball. The passage of a spark between two metal balls inside suffices to explode the mixture and project the ball. If a strongly-charged Leyden jar be discharged amongst some dry gunpowder, the duration of the spark is too short to inflame the powder; but if a bad conductor, such as a wet string, be introduced in the passage of the electricity betweeen the outside and inside coatings of the jar, the powder will be readily fired. If the discharge be passed through a glass tube filled with water, by plugging the ends of the tube with corks and passing in copper wires till they are within a quarter of an inch or so, the mechanical shock due to the sudden electrification and mutual repulsion of the water particles is sufficient to shiver the tube and scatter its contents.

951. The intensity and suddenness of the electric spark and light is well illustrated by causing a variously-coloured disc to be rotated very quickly. Of course in ordinary light the impression is a fusion of all the different colours; but if a strong spark from the jar or battery be passed near the face of the disc while rapidly revolving, so as to illuminate it for an instant, the individual colours start forth in surprising distinctness, just as if the disc were brought for a moment to perfect rest. The late Sir Charles Wheatstone found the duration of the spark to be $\frac{1}{24000}$th part of a second for a maximum duration, and in some cases less than the millionth of a second. From a calculation made by M. Arago, a millionth of a second may be taken as the ordinary duration of a flash of lightning. Admitting that this is only an approximation to the truth, it brings before us the extraordinary quickness of vision; for while the flash lasts all objects are visible to the eye, and yet the light whereby they are seen must be reflected from them in an inconceivably short period of time.

Thus, if a body in swift motion be illuminated by an electric or lightning flash, it will appear motionless for a moment. A cannon ball would appear to stand still in its course for an instant, and a falling sheet of water would be seen to be really discontinuous by the aid of the electric flash.

For a similar reason, in a thunderstorm during the night at sea, the waves, although in violent motion, appear to be suddenly petrified or at perfect rest during the lightning flash; and, under similar circumstances on land, the leaves and branches of the trees, although strongly agitated by the wind, appear to become suddenly still.

It may have been observed by those who have travelled in an express railway train at the rate of from sixty to eighty feet in a second, that near objects in a cutting, or on a wall or embankment, appear to lose their form and to fly past us with inconceivable rapidity. We see them, but they become greatly lengthened, owing to the duration of the impression on the eye. A large rounded pebble is no longer seen as such, but it presents the appearance of a brown streak, six or eight feet in length; and all bodies by the side of the road appear to run into parallel lines, just as a stick lighted at one end, when swung round with great velocity, appears to the eye like a circle of fire. Perhaps nothing can more strongly indicate the inconceivable velocity of lightning, than the fact that objects thus seen by the flash during darkness in railway travelling, appear in their proper shape and position, as if the motion of the train had been suddenly and completely destroyed.

If a strip of metallic foil, such as tinfoil, adhering to the surface of a glass plate or tube, have divisions or small open gaps cut in it, the interruption of an electric flash becomes visible at every one as a bright spark. Thus luminous letters or writing, consisting of dotted lines of light, are producible at each electric discharge, and many pretty devices can thus be exhibited.

The electricity of friction is capable of producing also magnetic and chemical effects; but as these are analogous to the effects more powerfully produced by galvanic electricity, they need not be here detailed.*

The Electricity of the Atmosphere.

952. By the lightning flash between a cloud and the earth, all the effects of the electric spark mentioned above may be produced in intensified degrees. Dr. Franklin, in the middle of last century, was the first to show the identity of the lightning flash with the electric spark. He sent up a kite into the air in the midst of a thunderstorm, having provided the kite with an iron point connected with the hempen string. To the lower end of the string an iron key was attached, and the latter again attached to a strong silk string, so as to insulate it from the hand of the person holding. After waiting some time he was able to draw an electric spark from the key with his knuckle; and a shower having improved the conducting power of the string, the philosopher was able to charge a Leyden jar with the electricity of the clouds, and so prove its identity with the ordinary excitement of the cylinder machine. The result of this experiment was the devising of pointed metal rods for leading the electricity of the clouds harmlessly to the earth, and thus saving life and property from the destructive force of sudden electric discharges of clouds.

The writer refers to this fact with particular interest, from having twice witnessed, during a voyage made in early life, before the adoption of the more substantial lightning-rods now generally supplied to great ships, the appalling occurrence of a ship insufficiently protected being struck by lightning. The first time was in the South Atlantic, where a mast was split, and of several men knocked down one did not recover; the second time, when the ship was at anchor in the Straits of Malacca. A part of the rigging was set fire to, but by prompt measures the ship was saved.

A badly constructed lightning conductor would, however, prove more dangerous than the absence of any protection ; and there are many instances of buildings having been set on fire through some fault in the insulation or conductivity of the lightning-rod.

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* The production of electricity by friction is remarkably exemplified in the escape of steam at high pressure from a steam-engine placed on a non-conducting surface. The friction thus produced generates electricity on a large scale, and thus sparks have been obtained from a locomotive placed on dry bricks, owing to the friction of the steam escaping from the valve. The engine-driver, in attempting to move the lever of a locomotive so placed, received a succession of shocks.

953. It is worthy of remark that, in every kind of weather, there is more or less electricity present in the atmosphere ; the quantity, and even the kind of electricity are constantly fluctuating, and the governing laws of these atmospheric changes, are but imperfectly understood.

If a well-insulated lofty metal rod be connected with a common gold-leaf electroscope, the nature and degree of atmospheric electrification overhead can be simply exhibited. Much more sensitive electroscopes have, however, been introduced in recent years, especially the *water-dropping collector* and others, by Sir W. Thomson. Constant observations with these at Kew Observatory show that the degree of atmospheric electricity, or the electric *potential* of the atmosphere, as it is now commonly worded, presents remarkable changes of variation, often within a few minutes.

Its fluctuations, in fact, are almost as variable as those of the wind, and, very probably, are closely connected with them. The following table will give an idea of the extraordinary changes in degree of this atmospheric element :—

Minimum potential (for a few minutes only) .	0·1
Low potential (rare occasions)	1
Average in fine weather	4
Average in fogs (always Positive)	10
Average in wet weather or snow (Pos. or Neg.)	20 to 30
High wind during frost (Pos.)	80 to 100
Thunderstorms, frequently (Pos. or Neg.) . .	100 or more.
„ sometimes (if Neg.) . . .	200

All observations agree in showing that the average degree of electrification is greater in winter than in summer. But no general theory of the cause of the variations, seems as yet to have been established.*

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* According to Professor Daniell, although the atmosphere is not usually so charged with electricity as to produce any marked or visible phenomena, yet it will commonly afford indications of electrical excitement. He found that in calm dry weather, when no clouds were visible, the gold leaves of an electroscope always indicated positive or vitreous electricity, the intensity of which was subject to regular variations reaching a maximum about seven

Current, Galvanic, or Voltaic Electricity.

By the chemical action of an acid on two dissimilar metals, a less demonstrative, but more reliable and serviceable, form of electricity is generated. It is produced in a continuous current, which may be conducted in any desired manner along a metallic path; hence it receives the name of current electricity.

954. It was not until the middle of the last century that the electrical machine was invented, as well as the Leyden jar and the electrical battery, and that Franklin proved the identity of electricity and lightning. The public mind was by these occurrences excited and gratified in the highest degree, and wonder was felt that facts of such vast importance, and apparently not deeply hidden, could have remained unknown so long; but scarcely had this feeling subsided, when a new set of facts connected with electricity drew attention, soon to appear of still greater importance than those above referred to.

Galvani, professor of anatomy at Bologna, having observed that some newly skinned frogs were convulsed when lying near an electrical machine, which he was working, commenced to experiment on the sensibility of dead frogs to the effects of electricity. Happening one day to notice a convulsive motion of the legs of a dead frog, which hung on an iron balcony by a copper hook, he was struck with the resemblance to the twitchings caused by the electric machine. On further examination, he found that when he joined with an iron or copper wire the nerves and muscles in the legs of a frog, the limbs were convulsed every time that the contact was made. He remarked, also, that the convulsion was stronger when different metals, such as iron and copper, were used, one touching the lumbar nerves and the other the muscles of the leg. Each time that contact was completed by connecting the two wires the limbs separated as by a voluntary action.

Galvani ascribed the effect to a source of electricity resident in the animal frame—the nerves having one kind of electricity and the muscles another.

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or eight o'clock in the morning, and falling to a minimum between one and two. In high winds and damp weather, without rain, electrical indications can rarely be obtained, and in cloudy weather and during the fall of hail, rain, or snow, they vary much as to kind and intensity.

Volta, another Italian professor, continuing the researches originated by Galvani, came to a quite different conclusion as to the seat of the electricity. He maintained that it was the contact of dissimilar metals or substances which was the exciting cause; and showed that by connecting the muscle with two different metals—iron and copper—the same effects could be produced.

955. *The Voltaic Pile.*—To support his theory that the mere contact of different metals was a source of electricity, Volta was led to the construction of what is known as the voltaic pile, shown in fig. 263. Piling a number of zinc and copper discs, separated by moist cloth discs, in the order,—copper, zinc, cloth—copper, zinc, cloth—copper, zinc, and connecting the last zinc with the first copper, he obtained much more powerful effects. So marvellous, indeed, were the effects of the combination that it astonished the whole scientific world, and gave an extraordinary stimulus to experimental researches generally.

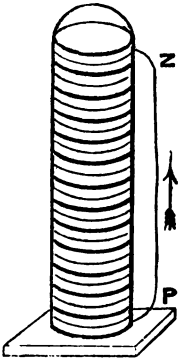

Fig. 263.

Without attempting to develope the historical growth and progress of the science, we shall merely give the leading results and facts, which is all that the present treatise calls for.

956. It is now considered by the highest authorities on electrical science that Volta was so far correct in his hypothesis that the contact of different metals is a source of electricity. If plates of pure zinc and pure copper be placed together they assume opposite electrical states—the one positive, the other negative—to their neutral or normal electrical state. In the language of modern electricians a difference of *electrical potential* is set up. Electrical potential is that quality or property in a body by which electricity (whatever electricity may be) tends to pass from it to another body, and is measured by the amount of resistance to its passage.

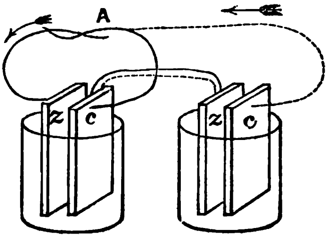

Fig. 264.

The passage of electricity from a body at a higher potential to one at a lower, is said to constitute an electric *current;* so that a lightning flash is to be regarded as a single current of momentary duration passing between bodies whose difference of potential is very great.

In order to produce a continuous current there must, of course, be some means of keeping the two bodies constantly at different potentials; this is nearly accomplished with a Holtz's electric machine. The passage of the electricity between the poles is so rapid as to be nearly continuous, and thus to constitute a sort of current electricity.

Chemical action, however, offers the most simple and easy means of supplying the constancy of different potentials, requisite for the continuous passage of the electricities.

If plates of pure zinc and pure copper be immersed in any acidulated solution, as, for instance, vitriol and water, the zinc and copper assume different electric potentials, just as if in contact; but so long as they are not connected in any way, the tendency of the electricity to pass from the one to the other is prevented. On joining the two plates, however, with a metallic wire, as in fig. 264, the electricity at once passes from the copper, or plate of positive potential, to the zinc or negative plate. This passage is accompanied with a series of very remarkable changes throughout the whole arrangement. If the connecting wire be dipped in iron filings it is found to have acquired magnetic properties; and the water of the solution is decomposed into its constituent elements oxygen and hydrogen. The latter gas bubbles up at the copper plate, and may be ignited with small explosions by applying a match there; the oxygen is liberated at the zinc plate, and by its strong chemical attraction for the latter, enters into immediate union with it. The compound zinc oxide which is formed is instantly dissolved by the acid solution, and so the zinc face is kept clean, and the requisite conditions for a constant difference of potential between the two plates are satisfied.*

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* The violent action of acids on commercial zinc is chiefly due to voltaic currents set up by the presence of foreign metals. Pure zinc is scarcely affected by acid of the same strength, and it is with difficulty that hydrogen can be obtained from it. If the bar of pure zinc is wrapped round with platinum wire or foil, a voltaic combination is formed, and hydrogen is evolved. A similar result is obtained with much less trouble by adding a few drops of a solution of sulphate of copper. The copper is deposited on the zinc and hydrogen is at once copiously produced.

Faraday, Davy, De la Rive, Daniell, and many more eminent philosophers, maintained that the real first cause of the electric phenomenon was the chemical action going on. The real explanation seems to be that both conditions—metallic difference and chemical action—are indispensable to the production of an electric current. "The flow of electricity is started, as it were, by the difference of potential due to contact; and the continued flow is maintained by the chemical decomposition of the liquid."

957. There is in some degree an analogy between electric potential, or electric action generally, and fluid gravity potential, or fluid action in general. Indeed the analogy between the two led to the original fluid theory of electricity; though the modern notions of energy give no countenance to the hypothesis. Water, with a head or potential energy, tends always to flow to a lower level; and compressed gas enclosed in a vessel will, when allowed to communicate with another vessel containing gas, with a less pressure or potential, flow towards the lower potential till there is an equalization of pressure.

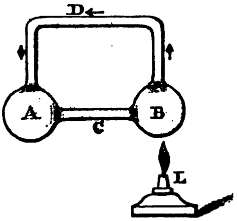

Fig. 265.

Another analogy to the electric current is illustrated by the figure (265). If A and B be two vessels of liquid connected by tubes or pipes, C and D, so as to form a complete circuit full of liquid, then we know, by the laws of heat, as already explained, that on heating the vessel, B, to a temperature greater than that of A, a current will set in, the warmer water rising up through the tube, D, towards the vessel, A, while cold water from A moves along the tube, C, to replace the heated liquid in B. This will continue until all the liquid is equally heated, and the source of heat is powerless to produce any difference of potential in the circuit.

The molecular excitement produced by the heat of the lamp, L, is analogous to that produced by the chemical action of the liquid on the one plate of the galvanic couple; but there is reason to conclude that the analogy is not complete, and that the electric flow is not a material flow along the connecting wire, as we have in the case of this liquid circuit.

Any arrangement, then, for producing electricity in a current, consists generally of a conducting circuit, with a dissimilarity of structure at some part, which is the subject of molecular disturbance;

and the galvanic element or cell is but a particular instance of the general class. The molecular disturbance may be produced by heat as well as by chemical action, and gives rise to electric currents exactly similar in character to those of the galvanic cell.

958. When several cells are united so that their effects may be combined, a galvanic or voltaic battery is formed.* The figure (fig. 266) shows one of the earliest combinations of this sort. It is called a trough battery; and consists simply of a trough, N′ P, divided by glass, or slate, or glazed porcelain, into a series of water-tight compartments. A number of galvanic pairs of metal plates are affixed to a wooden bar, N P, so that they can, when desired, be lowered simultaneously into the trough. The plate, N, is zinc, and forms the negative pole or terminal to which the conducting wire is fastened: the next pairs—copper and zinc—are each joined together by a band of copper; and so at the extreme end, P, a single plate of copper is left, to which the other wire or terminal is attached. The cells are filled with salt water, or water acidulated by $\frac{1}{12}$ of its volume of vitriol; and on immersing the metal plates in these a very powerful current flows through the wire connecting the terminals.

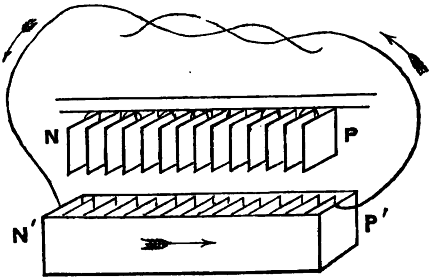

Fig. 266.

By uniting many such troughs very extraordinary effects may be produced, as the sequel will show. Sir Humphry Davy, at the Royal Institution in London, had a battery composed of two thousand pairs, with which he obtained astounding effects, and with which he made his principal discoveries.

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* Named respectively after two Italian philosophers, GALVANI and VOLTA, who discovered the facts.

Many improvements on this original form of battery have since been devised, to describe all of which is beyond the scope of the present treatise. We shall, therefore, explain briefly the action of the principal and typical forms which have proved themselves most efficient for experimental, as well as telegraphic and other practical, purposes.

959. *Daniell's battery and its varieties.*—Professor Daniell invented the form of cell represented in fig. 267, which for general purposes is still one of the very best forms. It consists of a copper dish or cylinder, C, within which is placed a porous dish of unglazed porcelain, which latter contains the negative element, a rod of cast-zinc, Z. Dilute acid acts upon the zinc in the porous dish, and a strong solution of blue vitriol, or the sulphate of copper, is placed between the porous cell and the copper element; some undissolved crystals being also placed in the solution to keep it strong or concentrated. The advantage of this compound arrangement is that the porous division—which might also be of bladder, or paper, or anything of this nature—prevents the passage of metallic particles between the copper and zinc elements, which takes place rapidly in the former arrangement where the two are placed face to face. Not only so, but there is an advantageous secondary action or effect of the current upon the sulphate of copper solution, by which the metallic copper is displaced from its union with the sulphuric acid and deposited bright and pure on the copper dish, thereby keeping its metallic surface clean and ready for constant action. These two qualities combine to make the battery in a remarkable degree constant and invariable in the strength of current which it evolves.

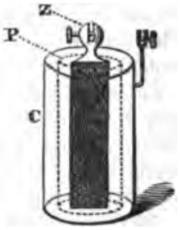

Fig. 267.

A combination of the Daniell principle with the trough arrangement explained above is now much employed for telegraphic purposes. Each of the water-tight compartments in the above trough (fig. 266) is simply divided into two by a porous diaphragm; the copper plate with blue vitriol solution goes into the one half and the zinc plate with dilute sulphuric acid into the other. Several other contrivances have been adopted for the purpose of dispensing with the porous separating plate altogether, and still keeping the liquids distinct. But the advantage of economy is counterbalanced by increased awkwardness in construction of the cells so as not to admit of ready inspection or repair.

The following modification of the Daniell cell has been found to work very well. A shallow glass dish, D, forms the outer vessel; it is half or third filled with fine clean sand. A ring of glass is pushed down so as to be about an inch under the sand surface. A strip of copper sheet, bent into a ring, is placed round the glass ring and forms the positive element or pole of the cell; while a rod or lump of cast-zinc, placed inside the glass ring so as to rest on the sand, forms the negative element. The action takes place through the sand, and the liquids can be replenished with great readiness.

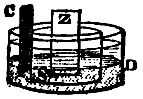

Fig. 268.

Callaud's battery is pretty much the same in principle as this, only less capable of ready inspection. In the latter, the copper plate is placed at the bottom of the cell among sulphate of copper crystals; the whole is covered with a layer of sand, and the zinc plate laid on the top of this.

960. *Grove's* battery and *Bunsen's* battery are perhaps the most important of all on account of their superior current-power, or *electro-motive force.*

Fig. 269 will give an idea of the Bunsen cell, which differs from Daniell's only in two particulars: first, a cylinder of coke or carbon, C, stands within the porous cell, taking the place of the copper in Daniell's, as the positive pole; and, second, this positive element is immersed in strong nitric acid instead of the cupric sulphate in the Daniell. The negative element, as in other batteries, is zinc, and the exciting liquid in the outer cell, dilute sulphuric acid. The Bunsen element is much more powerful than any of those we have described, and is very extensively employed on the Continent. In this country a variety of the same type of element more commonly used is known as the Grove element. It differs from the Bunsen only in the substitution of a platinum plate for the carbon of the former; and, though more expensive at the outset, a battery of this form is more economical in the end, and more cleanly to work with, than the Bunsen.

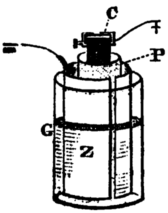

Fig. 269.

The purpose which the nitric acid serves in both of these batteries is to remove the hydrogen gas, which is liberated at the positive element by a series of decompositions and recompositions. It is found that when the liberated hydrogen is not removed, it reduces the power of the battery very rapidly, both by covering the positive plate with a non-conducting gaseous layer, and by an opposite electro-motive force which the hydrogen sets up. This secondary action is termed *polarization of the plates* of the battery, and in single fluid batteries, its effect is so great as to reduce their power very rapidly.

The *Maynooth* battery is a modification of the two last. Iron immersed in strong nitric acid, or in a mixture of strong nitric and sulphuric acids, is not attacked as we should expect, and as it naturally is, when immersed in a weaker acid solution ; not only so, but it is thrown into the passive state, as it is called, acquiring a sort of permanent unoxidisable skin over it, which enables it to be used as the negative element, instead of platinum or carbon, in the cells we have described.

To avoid the disagreeable and dangerous fumes of nitrous gas given off by all these three forms of battery, the *bichromate of potash* is proposed as a substitute for the nitric acid. It is mixed with five times its weight of vitriol, and ten times its weight of water, and the zinc is acted on by brine, or a saturated solution of common salt. But this battery is less reliable in its constancy, and its electro-motive force is less.

Marié Davy's sulphate of mercury battery is a recent ingenious modification of the Bunsen. In it, the carbon plate is surrounded with a thick solution or paste of the sulphate of mercury ; while the zinc is acted on by brine or weak acid. The liberated gas in the positive cell displaces the mercury from its combination with the sulphuric acid, and metallic mercury is deposited on the carbon, speedily collecting in drops and by its weight falling to the bottom of the porous cell.

961. *The Leclanché cell* is a cheap form of battery which has become popular within a few years. In it the plate of carbon in the porous cell, is packed round with a mixture of coarse carbon and binoxide of manganese ; while in the outer or zinc cell, a solution of chloride of ammonium or sal-ammoniac acts as the exciting liquid. This action causes the formation of chloride of zinc in the outer cell, and the liberated hydrogen reduces the manganese oxide to a lower oxide. When a long-continued current of no great power is required, as in short telegraphic circuits, or for electric bells, such a battery is said to be very suitable.

Such are the leading forms of the voltaic or galvanic battery which have been devised; but many others have been proposed and, to a greater or less extent, adopted. These do not require a special notice.

962. It may be stated as a general principle that any two metals having a difference in their degree of oxidability, or in their readiness to oxidize, may be used with a dilute acid to generate an electric current. The greater the degree of oxidability, the greater the electric current or electro-motive force of the couple. The order of oxidability for the principal metals is as follows :—

Zinc.
Tin.
Lead.
Iron.
Nickel.
Bismuth.
Antimony.
Copper.
Silver.
Gold.
Platinum.
Graphite or Carbon (a non-metal).

If we associate any two of these as a galvanic couple, we produce a current; and the farther apart the metals are in the list, the stronger the current produced. The current is always considered to flow up the list, that is from the metal least acted on to the other. Thus zinc-iron in dilute acid will give a current from the iron towards the zinc; zinc-copper, a stronger current; zinc-platinum, a stronger still; and zinc-carbon, the strongest current of all. This explains the superior power of the Bunsen and Grove arrangements of battery. No other combination in the list can, by the very nature of things, produce such a strong current when placed in dilute acid. It may be observed, however, that this order is by no means invariable for all acids; with a difference in the nature of the exciting liquid, considerable variations in the order are introduced.

Two liquids also, having different affinities for any metal, will give rise to a current when united by a single wire or plate of this metal. For example, if in a Grove cell, the zinc and sulphuric acid be replaced by a strong solution of caustic potash, and if the nitric acid and the potash be connected by a platinum wire, a current will flow from the nitric acid towards the potash.

963. In the manipulation of batteries the following points should be attended to :—(i.) The metals used for the poles or electrodes should be as pure as possible; this prevents the interference of minute *local currents*, which consume the plates unnecessarily and weaken the general current materially. Pure zinc is very expensive, the common commercial article containing several impurities, such as arsenic, iron, and carbon; but it has been found, though the reason does not seem very obvious, that rubbing the zinc plates over with some mercury makes them as good for the purpose as if the zinc were chemically pure. In all cases, the zinc plates should be well rubbed in this way or *amalgamated* as it is technically termed.*

(ii.) The wires used for conducting the current should be of pure metal. Copper is commonly used, and it was discovered by Matthiesen that the impurities, usually present in this metal, seriously affected its conductivity. Thus the presence of a small quantity of arsenic in copper, greatly destroys its conducting power.

(iii.) All connections between pairs, should be as perfect as possible; and should be looked to occasionally, as the corrosion of these would very strongly impede the current.

(iv.) The proper strength of acids must be maintained, and, instead of dilute sulphuric acid, a solution of sulphate of zinc may be employed with advantage in the zinc cell of any of the batteries we have described. The deposition of sulphate of zinc crystals on the porous cells should be prevented; and porous cells after having been in use for some time should not be emptied and set aside, but should be kept full of clean water.

The conducting power of the different metals for the electric current nearly corresponds to the order observed for conducting heat (Art. 591, p. 404). Among non-metals it is remarkable that charcoal, which does not conduct heat, is a very good conductor of electricity. Among metals, silver, copper, and gold are the best conductors, and lead, platinum, and mercury, among the worst. A current which will pass through a silver wire without producing any apparent change, will heat a platinum wire of the same diameter red-hot. In current electricity, the force passes through the entire thickness of the conducting metal, and not, as in static electricity, by the surface only. Small wires of platinum are thus easily made red-hot by the current, and are used for exploding gunpowder in military mining and submarine operations. In reducing the thickness of the conducting wire we thus intensify the heat, by making a larger quantity of electricity traverse it in the same time.

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* The amalgamation of the plates renders the battery extensively applicable to many purposes in the arts. It was first suggested by Mr. Kemp. According to Mr. Smee, the mercury used in amalgamation envelopes the carbon and foreign metals, and therefore the first gas evolved adheres so firmly to these that every foreign point of metal becomes coated in such a manner as to prevent further action. Of all metals known, there is none to which the hydrogen adheres so firmly as to mercury.

Heated wires do not conduct so well as those at a low temperature, so that the heat acquired by a platinum wire tends to retard or even to destroy its conductivity.*

For general purposes, where constancy of current more than power, or electro-motive force, is required, as, for instance, for telegraphic purposes, there seems to be no better form of battery than that devised by Daniell; which when properly attended to, will keep for months in action.

In the cellars of the Central Office, in Telegraph Street, there are some thousands of cells, and the form of battery adopted there, is a modification of the Daniell; the fumes arising from the Grove and Bunsen batteries render the employment of these in such circumstances impossible.

Galvanic deposition. Electro-plating.

964. The deposition of metallic copper from the cupric sulphate solution, which, as we have explained, takes place in the Daniell cell, has been turned to practical use in the deposition of other metals as well as copper, such as gold and silver, from solutions of their salts, and the extensive modern art of electro-plating has grown up from the application of this simple fact.

Electro-plating is the deposition of a thin layer of one metal on the surface of another, either, as in electro-silvering, or electro-gilding, to give an inferior metal all the appearance and lustre of the more valuable ones, or for protective purposes, as when nickel is deposited on iron or steel to prevent their oxidation. In any case, the process employed is very much the same. Thus, in electro-plating a copper spoon with silver, the copper spoon is immersed in a solution consisting of 1 part cyanide of silver, 10 parts cyanide of potassium, 100 parts distilled water; alongside of it is immersed a plate of silver; the copper is then connected with the zinc pole of a Daniell's battery, or cell, while the silver plate is joined to the copper pole of the Daniell, and by an action precisely akin to that of the simple cell itself, the spoon is gradually covered with a strongly-adhering layer of silver. The process will occupy a day or two, according to the strength of the exciting cell or battery; but the slower the process, the more cohesive will the deposited coating become.

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* Intensely heated metals are absolute non-conductors of electricity. Mr. Sandy states that at a great fire in Tooley Street, some years since, when he was chief of the Telegraph Department at Brighton, the flames reached the wires and made them red-hot. While they were in that condition the communication with London Bridge Station was as completely cut off as if the wires had been actually severed.

Electro-typing, electro-casting, or electro-moulding, is the depositing of a thick layer of a metal, such as copper, from a solution of its salt, the object being a substantial copy or re-production of a coin, engraving, or other object The general process differs from the former only in minor details, and we need but remark that where the original cannot be employed as the actual mould for the electro deposit, a cast of it may be taken in plaster-of-Paris, or in gutta-percha, wax, or paraffin, the surface of the mould being then carefully brushed over with finely-powdered plumbago or black-lead, to give to it conducting power.

In this way faithful copies of antique coins or seals are easily produced, and copper-plate engravings may be multiplied to almost any extent, without losing much of the delicacy of the original. Even wood engravings can thus be turned into copper-plates; and, more wonderful still, the microscopic definitions and elevations of the silverized surface of a daguerreotype plate can be reproduced in relief by this same process.

The applications of this process of depositing a thin metallic layer on a body prepared for its reception, have developed into an extensive art, the art of *electro-metallurgy*, relating to which hundreds of patents have been taken out in this country: patents for coating steel pens and pen-holders, for coating the soles of boots and shoes, for coating chairs, bedsteads, and other household articles, for gilding thread and wire-gauze, for making copper tubes and vessels, for coating the hulks of ships and for making coffins, for printing and engraving, for protecting telegraph-wires and cables, for ornamenting sepulchral monuments, for metallizing fibrous materials, leaves, or fruits, and even for metallizing a human corpse.*

Electrolysis or Electro-analysis.

965. The study of the actions going on at the two poles of a galvanic cell or battery has also led to applications of as great importance to the chemist, as those of metallurgy to the world at large; it has, in fact, created the distinct department of chemical science known as Electro-chemistry.

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* See a volume printed by order of the Commissioners of Patents, entitled 'Abridgments of Specifications relating to Electricity and Magnetism.

When an electric current passes through a practically perfect conducting liquid, such as a molten metal or mercury, there is no alteration in the molecular structure of the liquid; but when the liquid is of a compound nature, and offers more or less resistance to the passage of the current, then decomposition of the liquid invariably occurs, one of the elements appearing at the positive pole, and the other at the negative. In accordance with the analogy of electric attraction generally, the element which is drawn to the positive pole is called the electro-negative one, and the element drawn to the negative pole, the electro-positive one.

966. *Decomposition of Water.*—Of course the two poles, that is, the extremities of the two wires from the end plates of the battery, must be of a kind not to be chemically acted on by either of the liberated elements. They are generally of platinum, and the decomposing apparatus may be arranged as in the figure 270.

Here we have the wires from the zinc and copper poles of a battery connected with the platinum plates, P P, immersed in water; the ends of the wires which are soldered to the platinum plates are carefully covered with gutta percha, otherwise a secondary decomposition of the wires would ensue. In the first place, if the platinum plates be immersed in pure water, no decomposition takes place at all, the reason being that the water has not a sufficient conducting power. On the addition, however, of a small quantity of vitriol or sulphuric acid, the necessary conducting power is acquired, and hydrogen and oxygen bubble up at the two poles, the hydrogen at the zinc pole, or platinum connected with the zinc end of the battery, and the oxygen at the positive or copper pole. We may suspend two glass tubes over the two plates, provided, as in the figure, with india-rubber tubes and clamps at the upper ends, by which means we can easily fill at pleasure the glass tubes with the liquid under examination. With acidulated water we shall find that pure hydrogen rises up into the one tube, and pure oxygen into the other, the hydrogen forming twice as fast as the oxygen. If both

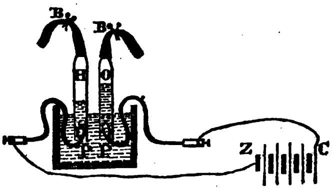

Fig. 270.

gases be collected in one receiver, and combined again by explosion with a light or otherwise, they disappear entirely, and pure water is formed, showing that the sole effect of the sulphuric acid in the liquid is to conduct the current, and that the gaseous products are the decomposed elements of the water. If two copper plates, or the ends of two copper wires, were simply immersed in the cell of acid, the nascent or new-born oxygen would attack the positive pole, and combine with the metal as oxide (or sulphate) of copper, while the hydrogen alone would appear at the other.

Suppose, again, that we substitute hydro-chloric acid for the water in this apparatus, it is found that hydrogen appears, as before, at the negative pole, and chlorine gas at the positive pole.

If solutions of metallic chlorides be substituted for the hydrochloric acid, as, for instance, chloride of copper, or of gold, the metal appears as a precipitate at the negative pole where the hydrogen appeared, and the chlorine at the positive pole. Thus, hydrogen, copper, and gold are all classed as electro-positive elements, while oxygen and chlorine are electro-negative elements. The decomposition of other salts as well as of alkaline solutions, may be effected in the same way. It was by this means that Sir Humphry Davy, after effecting the decomposition of water with a battery of 250 cells, was led to the discovery of the metals potassium and sodium, as the bases of the alkalies potash and soda, formerly supposed to be elements.

It is to the illustrious Faraday, however, that we owe the full development of the laws of electrolysis. He showed that if the same electric current traverse a series of different chemical compounds, the quantities of the different elements decomposed in its passage, are exactly proportional to the chemical or atomic equivalents of the elements. Thus, for example, if an apparatus such as that represented in fig. 270, and several U tubes containing, say, chloride of silver, chloride of tin, and oxide of lead, be all inclosed in one circuit, through which a strong current is passed, the electro-negative elements will be simultaneously separated at the positive poles, and the electro-positive elements at the negative poles, while the quantities decomposed, will be in the proportion of 1 hydrogen to 108 silver, 58½ tin, 103½ lead, 55½ chlorine, and 8 oxygen, that is, *in the proportion of the atomic weights of the elements.*

This theory of electrolysis, and the atomic theory of chemical action, thus mutually strengthen each other. Faraday also established the law that the quantity of any compound decomposed in a given time, say a minute, is proportional to the strength of the current, and consequently may be taken as an estimate of its strength. He used an instrument akin to that already described (fig. 270), with graduated tubes, as a *Voltameter* or absolute current measurer. It is chiefly available, however, only for strong currents, and for estimating their average strength during a shorter or longer period. The magnetic effects of the current, as will be explained, offer a much more ready and delicate test of current strength.

SECTION IV.—MAGNETISM.

967. Formerly, in systematic treatises on Natural Philosophy, magnetism stood apart as a very distinct branch of science, singularly at variance with the general course of nature; but recently, since more extended knowledge of both electricity and magnetism has been acquired, the resemblances between them are found to be so numerous and close, that nearly all the phenomena can be referred to the same influences.

When the most obvious facts of magnetism first attracted notice, nothing could appear more strange or inexplicable. A dark-coloured heavy stone, now met with in many parts of the earth, but first observed near a village called Magnesia, in Asia Minor, from which it derived its name of magnet, was found to have the singular power of drawing towards it pieces of iron or steel, and of lifting them into contact, and there supporting their weight for any length of time. It is referred to by more than one ancient writer, and Pliny states that this iron ore was called by the common people *ferrum vivum*, that is, living, or quick iron; because it seems to endow small masses of iron with life. This natural magnet, or loadstone, known to the mineralogist as magnetic iron ore, is found in Sweden and other parts of the world; being so abundant in some rocks and mountains, as to produce a disturbing magnetic effect on the compass-needles of ships which may pass near them. It is known to the chemist as the magnetic oxide of iron. It is of a different atomic constitution from the common oxide of iron, or iron rust.

On rubbing this stone against rods of steel, its power of attracting iron can be communicated to the steel, and then, from one bar of magnetized steel, other bars can be magnetized without there being any diminution of force in the original or giving bar. A good illustrative experiment is to show a common iron key hanging by magnetic force to the end of a magnetized bar, as shown in fig. 271.

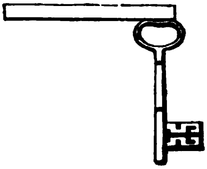

Fig. 271.

This communicative power of the loadstone was in all probability known to the ancients.

968. *Polarity of the Magnet.*—Such a stone or magnetized rod of steel, if suspended by a string or poised on a pivot, so as to have freedom of horizontal motion, soon places itself with one of its sides or ends, and always the same, towards the north pole of the earth, and with the opposite, consequently, towards the south pole. Its own corresponding sides or ends so discovered, are called the *poles of the magnet.* If the stone or needle be by any force disturbed from the position so taken and then left free, it always of itself returns to the same. A common sewing needle magnetized, and laid gently on the surface of water, will turn north and south in the same manner.

This property, called the polarity of the magnet, has often been referred to as one of the most curious facts in nature, and is of vast importance to mankind; for men are often placed in such circumstances that their safety, or even life, may depend on their being able to judge correctly of the directions, north and south. A man, when there are dangers near, may be suddenly enveloped in a thick fog, or in a blinding fall of snow, or he may lose his way in traversing a forest, or on crossing an extensive plain without distinguishing objects on its surface, or in a boat he may be driven by a storm out of sight of land; in such cases life may be lost, if he judge erroneously of his position or of the direction in which he moves. In any such dilemma, a magnetic needle, even so small as to be carried in a seal attached to his watch, would insure safety. Had the mariner's compass, which is only a larger needle fitted to bear the tossing of the waves, not been invented, the intercourse of nations by sea could scarcely have taken place. In remote past times, nothing could have seemed more incredible than that a stone would be discovered in the bowels of the earth, which could point always with certainty to the pole, for which the highest human sagacity without it, would search in vain.

Though the Greeks and Romans do not appear to have been acquainted with the polarity of the magnet, the Chinese have in all probability been acquainted with it from a remote period, their name for it meaning *the directing or guiding stone.* It is asserted by the earliest English writer on magnetism (Dr. Gilbert) that the first compass was brought to Europe from China, in the middle of the thirteenth century.

969. *Mutual action of Magnets.*—If two poised magnetic bars are brought near to each other, the poles of the same name, north or south, are found strongly to repel each other, and the poles of different names strongly to attract; but either pole is equally attractive of non-magnetized iron or steel. In these facts there is a striking resemblance to the phenomena in electricity of bodies similarly electrified, whether positively or negatively, being held apart by strong mutual repulsion; and of bodies, if dissimilarly electrified, strongly attracting; a magnetized body, like an electrified body, attracts another in a neutral state.

If a magnetic bar or needle be placed for an instant among iron filings and then be lifted, it lifts with it a considerable quantity of the filings cohering around the ends in tufts or lines of particles as here shown, but there are none cohering near the middle of the bar. This experiment indicates the different force of the attraction at different distances from the poles of the magnet, and the non-attraction in the middle part about the so-called equator.

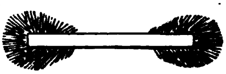

Fig. 272.

From this experiment it also appears as if the magnetic strength were localized near each end of a magnetized bar. This may be also very beautifully exhibited by laying a flat magnetized bar, such as a straight piece of watch-spring, on a sheet of paper, marking its position, and moving round each of the ends of this fixed magnet a small sewing needle magnetized and hung up by a silk fibre. If the point of the sewing needle be a north pole, and the eye end a south pole, the positions of the needle will be as indicated in fig. 273. At the middle of the magnet the small needle will lie parallel to the big magnet, the attractions of north and south being just equal in amount and opposite in direction.

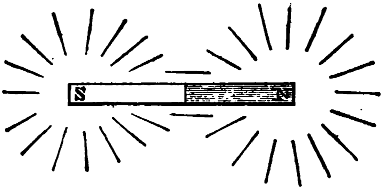

Fig. 273.

A very instructive variation of this experiment is to place the magnetized bar, or bar-magnet, as it is usually termed, under a piece of glass and sift fine iron-filings over the glass; after tapping the glass gently, the iron-filings will be found arranged as so many minute needles, and by their mutual action joined together, so as to form beautifully regular lines radiating from the poles at each end as a centre. Using two bar-magnets, and placing them, first, with like poles near each other, and, secondly, with unlike poles near, the conjoint effect on the iron-filings may be readily studied. The curves assume in these instances very symmetrical forms round the centres of magnetic force. They are known as the *Magnetic curves*, or Faraday's *Lines of Magnetic force.*

The analogy between electricity and magnetism is further strikingly exhibited by magnetic induction or action at a distance; the laws of which are precisely identical with those of electric induction.*

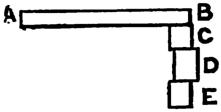

Fig. 274.

970. *Magnetic Induction.*—Simple contact, or the near approach of a magnet and a piece of soft iron, renders the iron for the time magnetic—very much as any insulated conductor of electricity, if brought *near* to a highly electrified body, becomes for the time electrical. Thus, the magnet, A B (fig. 274), attracts and supports the piece of iron, C, and that becoming magnetic, similarly supports the second piece, D, which again can support E. None of the pieces of *soft* iron, C, D, E, retain anything of the magnetic quality after the contact ceases. Pieces of steel after a time might retain a portion. It is in this way that the lines or threads of iron-filings in the preceding experiment are formed. With a strong magnet a line or chain may similarly be formed with iron nails or steel pens; each, becoming magnetic by induction, renders its neighbour in turn a magnet. Thus, with a curved magnet, a pliable magnetic arch may be built up between the poles with iron brads or tacks.

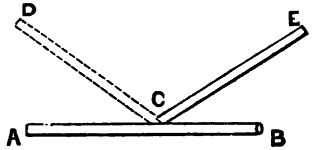

Fig. 275.

971. *Magnetization.*—A magnetic steel-bar, however, if fitly used, imparts its properties permanently to other steel bars, without losing any part of the power which it possessed itself. The common procedure thus to magnetize is, to apply at the centre of the new steel bar, as A B, laid on a table, one end of a strong magnet, C E, held obliquely, as here shown (at an angle of about 30°), and then to draw the magnet steadily along, held at the same angle, to B. After repeating this touch several times on one side, the other end of the magnet, E, is brought to the centre of the bar, C, and is drawn along to A, and an equal number of passes being made as from C to B, the bar, A B, is permanently magnetized. Instead of thus using a single magnet, C E, for both ends, two similar magnets may be applied at the same time.

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* The reader will observe the remarkable difference in the mode of distribution of the two forces in a similar bar. Electricity is diffused over the whole surface of the bar, and is as much manifested in the centre as at the two ends. Magnetism flies to, and concentrates itself in, the ends of the bar or poles. There is no manifestation of this force in the centre.

A bar of iron or steel, by merely lying long near a strong magnet, may become magnetic by influence or induction. Now this great globe which we inhabit, is proved by its influence on the compass needle to behave exactly like a huge magnet stretching from the north to the south pole; and in like manner a large mass of iron, or a bar of steel, lying long in the N. and S. direction acquires magnetism by the inductive influence of the earth. In this way, without the possession of any magnet at all, we may easily procure one for ourselves: holding a bar of tempered steel in the north and south line, and striking it a few times with a hammer on one end, we get a magnetized steel bar, or a bar-magnet, directly produced by the power of the earth. Workmen's tools, or a steel poker, are thus almost always found to be more or less magnetic.

972. *Theory of Magnetism.*—In searching for an explanation of this curious unseen power of attraction,—for the mind of man is never satisfied until it perceives all the connecting links between cause and effect,—philosophers have held several different theories.

The simple view of the primitive philosophers supposed the existence of two material magnetic fluids of opposite character; an accumulation of the one at the north pole, and of the other at the south pole, was all the explanation of magnetization which this required. But the phenomena of electric currents, besides many others observed in modern times, require some totally different hypothesis. There can be little doubt that magnetism is a molecular affection. For, in the first place, if a steel bar-magnet, such as a magnetized piece of watch-spring, be broken in two, each part is as complete a magnet as the original; and however often we break it, the minutest fragment is a perfect magnet, showing that the polarity or duality of character which the original bar possessed is equally a property of its every molecule. In the second place, magnetization is accompanied with molecular disturbance. It has been found by Joule, of Manchester, that an iron bar becomes slightly elongated when magnetized, while its width is correspondingly reduced; just as if there were a re-arrangement of the molecules among themselves, as if each turned round and set with its greatest length in the axis of the bar. In the third place, *heating*—and this we have seen is a molecular affection—or striking a magnet disturbs, or may even destroy, its magnetism.*

The molecular theory of magnetism is supported by many other considerations. If a thin glass tube be filled with steel-filings, and a strong magnet passed along it several times, it is found that the whole tube acts as one magnetic bar, having its ends oppositely magnetized; on disturbing the arrangement of the filings by shaking it, we find that every trace of the polarity has vanished. The electric current, again, is due, as we have seen, to molecular motions or disturbances in the cells of the battery, which are transmitted along the wire; and it accords with the molecular theory of magnetism that the flow of such a current round a bar of soft iron, produces the magnetic state of the iron. This is, in fact, one of the readiest as well as the most powerful ways of magnetizing a steel bar, or of producing temporary magnetism in an iron bar. For there is this remarkable difference between iron and tempered steel—due also to the change of molecular character in the latter—that, while a bar of iron can be much more readily magnetized in this way by a coil of cotton-covered wire conveying a current round it, yet it cannot acquire a *permanent* magnetic state. It is magnetic only so long as the current flows. On the other hand, a bar of steel does not take up the magnetic molecular arrangement with such facility as the soft iron; but it is all the more permanent that it is slow. The cause is considered to be, that in the tempered steel the particles, or molecules, are not so readily wheeled round into the required *set* direction as in the soft iron; or that the soft iron molecules are in fact the *more fluid* of the two.

973. *The Electro-magnet.*—Fig. 276 represents a convenient form of a powerful electro-magnet; it consists essentially of two coils, C C′, of thick cotton-covered copper wire, which are fitted on two massive iron rods connected at the bottom by a thick flat piece of iron, I, which, being screwed in the wooden base or stand, serves to keep the magnet upright. Two movable masses of soft-iron, P P′, serve as movable poles of the magnet, which may be adjusted in any required position. If the two poles, P and P′, be placed with their flat ends meeting, and a strong current, say, that from four to six Bunsen or Grove cells (see Art. 961), the two pieces, P P′, will be locked fast together, so that it will be impossible to separate them by the mere hand. But the moment the current is stopped, as by removing one of the wires from the binding screw, S, the magnet is shorn of its strength, and the iron becomes powerless as before. There is no limit to the strength of a magnet which may be thus constructed; tons may be supported in this way, and dropped as by magic through the mere touch of a child removing the current-conveying wire. If a piece of stout pasteboard be laid over the poles of such a magnet, and a heap of iron filings inverted on the pasteboard, they become like a soft viscous mass, which may be baked almost into any shape, or the filings will sprout up into shrub-like forms as if they were endowed with a sudden living power of growth.*

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* The effect of heat admits of easy demonstration. Let a suspended magnet be placed near a bar of iron, about eight inches long and about three-quarters of an inch square in section, so that the magnet is drawn out of its north and south position. The bar should be laid on a brick. If the end of the bar is now made red-hot, and replaced in its position near the magnet, it will be found that the magnetism of the bar has entirely disappeared, and the magnet flies off to the north. As the bar cools, and reaches a low, black heat, the magnet is drawn from its position, and is again attracted by the cold bar. Heat appears here to replace temporarily magnetic force.

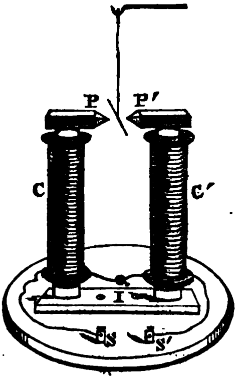

Fig. 276.

974. *Diamagnetism.*—But, perhaps, the most remarkable revelations which such a powerful magnet makes are, that, although iron and its varieties are apparently the only magnetic substances, still all bodies are in a greater or less degree affected by magnetism. It has been detected by means of powerful steel magnets that nickel and cobalt were feebly attracted by the magnet, while bismuth and antimony were repelled. These, however, were only known as supposed curious exceptions to the general non-magnetic character of all other metals. Faraday, with a powerful electro-magnet, was the first to prove that all substances fall under one or other of the two classes named by him *paramagnetic* and *diamagnetic.* Substances belonging to the former class are attracted by the magnet, and a little rod of a paramagnetic substance sets lengthways between the pointed ends of the movable poles of the magnet; it includes the metals *iron*, *nickel*, *cobalt*, *manganese*, *chromium*, *palladium*, and *platinum*; also *oxygen gas* and *air.*

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* In an experiment at the Royal Institution, Faraday suspended to his powerful electro-magnet, two sets of heavy fire-irons and a coal-scuttle full of coals. The watches of many of his audience sitting on the front benches were seriously damaged by reason of the inductive influence of this powerful magnet operating for a considerable distance.

Diamagnetic bodies, on the other hand, are repelled by either pole of a magnet, and a diamagnetic bar sets as represented in fig. 276, not lengthways, but right across the direction of the poles; of this class are *bismuth*, *antimony*, *mercury*, *lead*, *tin*, *silver*, *zinc*, *gold*, *copper*, *water*, *alcohol*, *sulphur*, *resin*, *wax*, *sugar*, *starch*, *wood*, *ivory*, *leather*, *bread*, and other organic substances.

Professor Tyndall has also found that crystals, when suspended between the poles of an electro-magnet, behave in such a way as to show that there is some intimate relation between what is known as their optic axis and the line of most powerful magnetic action.

The theory of magnetism which is known by the name of *Ampere's theory* is, that the magnetism of a steel bar is akin to that of the electric current; in fact, that minute electric currents (whose origin and source are, however, beyond speculation) circulate round the component molecules of a steel magnet; the difference between an unmagnetic and a magnetic bar being that, in the latter, the electric currents are all disposed in one direction, whereas in the former they are in all different directions, and so mutually destructive.

A similar theory has been advanced to account for the magnetism of the earth; huge electric currents circulating round our globe, and caused probably by the thermo-electric action of the sun's rays, are considered quite a legitimate and sufficient explanation of the phenomenon.

TERRESTRIAL MAGNETISM.

975. It might be supposed, at first, that a magnetic needle free to move, say, hung up by a very fine fibre, or floating on water on a cork support, would be drawn towards the north pole of the earth; but we must remember that if the point of the balanced needle be attracted by the north pole of the earth, then the eye end is also repelled by it; and the force of repulsion will differ from the force of attraction by an inappreciable

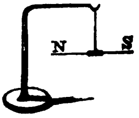

Fig. 277.

degree, seeing that the difference of the distances of the two poles from the north pole of the earth is less than the hundred-millionth part of the whole distance. There is a like attraction and repulsion by the south pole of the earth on the two ends of the needle; hence the resulting action is merely ***directive***, that is to say, merely turns the needle round, so as to lie in the line of these two opposite forces.

For a similar reason, two magnetic needles, A and B, of exactly equal strength, if fixed together with their two poles reversed, as in fig. 278, assume no particular direction as regards the earth; while they still exert and exhibit their separate powers on objects near to them. Such a double needle is called *astatic*, or without fixed direction.

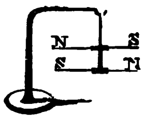

Fig. 278.

976. *Variations of the Compass.*—It is, however, an important and singular fact, to be noted, that the compass-needle does not point exactly north and south, that is to say, the magnetic poles do not quite coincide with the poles of geography, and that the amount of deviation, called the variation or *declination* of the compass, gradually changes in the course of centuries, being sometimes a little to the east and sometimes a little to the west of the earth's pole. The deviation, however, can be accurately ascertained by referring to the stars. In London, at present, the needle points about 19° to the west of north; in other words, to find the direction of the *true north* from a compass, we must reckon it 19° to the east of the direction of the needle, a point corresponding nearly to the position of the north pole-star. In the year 1657, more than two hundred years ago, there was in England no deviation of the compass, its direction being true north and south. Prior to that year, it had deviated to the east of the true north; but after that year, it slowly deviated more and more towards the west, till it attained a maximum deviation about the year of the battle of Waterloo. Since then its westerly declination has been slowly lessening, being now very nearly 19° west.*

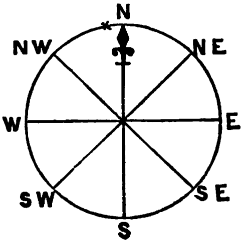

Fig. 279.

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* In 1576 the variation was 11° 15′ E. The needle gradually fell back to the north, and from 1657 to 1662 it pointed due north. It then passed to the west of north, reaching 8° west in 1700, and 24° west in 1800. The

Besides this slow change of declination, taking centuries to effect in any appreciable degree, there is a daily variation or change, which, with a needle delicately adjusted for the purpose, can be detected, in which it appears to follow the sun in his course in the heavens. It has been thought that a slight magnetic influence in the needle can also be traced to the position of the moon; but no exact deductions have yet been drawn on this point. There are also sudden and unmistakable disturbances of the needle co-incident with brilliant displays of the *aurora borealis*, and with volcanic eruptions; to these the name of *magnetic storms* is given when they are very violent.

977. *Dip of the Needle.*—In the *mariner's compass* the needle is so balanced on its pivot as to be horizontal in all parts of the earth; but if the needle is free to turn also on a horizontal axis, it will be horizontal only near the equator, but at other places it will dip down, pointing to the nearest magnetic pole, as here shown at B, D, and E. A needle so arranged is called a *dipping needle*.

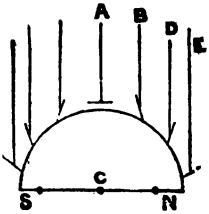

Fig. 280.

The degree of *dip* or *inclination*, as it is termed, varies for different latitudes; and is also subject to *secular*, *diurnal*, and *temporary* changes, as well as the declination. Like the declination, the inclination is decreasing at the present time in this country, being about 68° near London, whereas in 1723 it was very nearly 75°.

The dip of the needle was first discovered by Robert Norman in 1576; in adjusting a compass-needle he found that, having accurately balanced a needle before magnetization, it would not balance after being magnetized, but required a counterpoise at the south end.

978. *Magnetic Charts.*—The amount both of inclination and of declination varies with different spots on the earth's surface; and from an immense number of observations made by scientific travellers and nautical men, such as Humboldt, Ross, Parry, and Scoresby, *magnetic charts* have been drawn up, in which the places of equal

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variation gradually fell to 23° in 1842, and at the present date, thirty-four years later, it has fallen to 19° W. It occupied 153 years in reaching its maximum westerly variation, and is now apparently on its way back to the north.

declination, or of equal inclination, are marked by lines drawn through them. The chart line passing through all places of no declination is called the *agonic* line; and, roughly speaking, we may say that lines of equal declination form parallels to this line; but in no case are the lines very regular. Similarly, the chart line passing through all places of no dip or inclination, which may be called the magnetic equator, is called the *aclinic* line; and lines of equal declination, called *isogonic* lines are, roughly speaking, parallels to this. It is worthy of remark that in the case of iron ships, or iron-plated ships, now so common, a large degree of magnetism is often produced by the rivetting and hammering incidental to their construction. This is owing to the inductive action of the earth, and varies, therefore, with the position in which the ship has been built. If it has been built lying north and south, the magnetism induced will be very strong, and will have a very decided influence on the direction of the ship's compasses whenever the ship is sailing out of this line.* Before undertaking voyages with such ships, great care must be used to ascertain exactly the effect of this permanent magnetism imparted to the vessel; and cases have occurred where inattention to the disturbing magnetic effect of an iron cargo, shipped after an inspection of the ship's compasses, has had the most disastrous consequences.

ELECTRO-MAGNETISM.

979. The development of magnetism in soft iron, by a galvanic current circling round it in a coil, is but one of the manifold phenomena which go to make up the distinct branch of electrical science known as electro-magnetism. Currents, in virtue of their magnetic effect, attract and repel currents: they attract and repel the poles of a magnetic needle; and they are themselves also attracted and repelled by magnets. Second only to the original discovery of Galvani and Volta, was the discovery made by Professor Oersted, of Copenhagen, in the year 1819, when he found that the natural direction of a magnetic needle was instantly changed by its being near a voltaic battery in action. Such a needle happened to stand on a table where the wire of a battery lay parallel to it. It had its usual direction of north and south, when the battery was not acting, but the moment the current was allowed to pass, the needle was thrown or deflected into a position across the wire, and so remained as long as the current continued. On the current being stopped, as by unclosing or breaking the voltaic circuit, the needle immediately resumed its natural direction. Pursuing the investigation, Oersted found that the movements of the needle were produced as often and as quickly as the acts of closing and breaking the circuit could be repeated. He further ascertained that, near the wire, the changes took place as certainly and rapidly at any distance from the battery, as near to it; a simple fact within which lay concealed the coming prodigy of the *electric telegraph*, as will be explained some pages hence.

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* The great iron ship *Northumberland* was built in a north and south direction, and it was found when completed, after many months, that the vessel had acquired magnetic polarity on a large scale at the stem and stern.

On closer examination we find that the relations between the simple magnetic needle and the voltaic current are not quite so simple as might appear from this single statement of Oersted's experiment. Fig. 281 will serve to make this connection more clear.

If the line, A H F, represent part of the conducting wire-circuit of a voltaic battery, running from south to north, supported by the standards, H and, F and if two magnetic needles, N S, N′ S′, movable on pivots, are placed near it, one needle being below the wire, the other above it; then the moment that an electric current or wave is allowed to flow along from H to F, as marked by the arrow, both

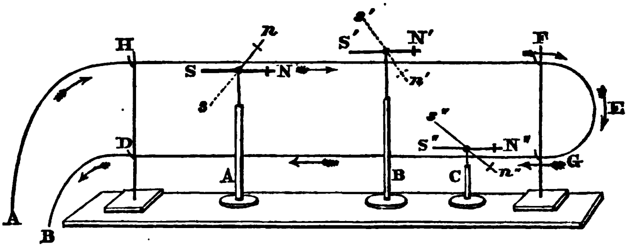

Fig. 281.

needles are simultaneously turned aside; but the one below turns its north pole N to the west, as shown by the dotted line, *n s*, and the other above turns its north pole, N′, to the east, as shown by the line, *n′ s′*. If the wire be bent at F, so that the current flows back below in the direction, G D, the effect of the current in G D, on a needle, N″ S″, above it, will be to turn it to the same hand as the upper current in F H turns the needle, N S, below it. These apparently contradictory facts are all united under the following simple rule known as *Ampere's rule; viz.,*

> To a person supposed to be swimming along with the current and with his face to the magnetic needle, the north pole of the needle will appear to turn to his left.

980. A remarkable consequence arises from these facts, namely, that if the wire of the voltaic current, A E (fig. 282), over the needle, S N, be bent down at E, and carried back to G, at a short distance below the needle, instead of counteracting the influence of the upper part of the wire, A E, as might be expected from its electric current being in the contrary direction to that in A E, it doubles the effect. The part of the rotating or wheel current about the upper wire, which acts on the north pole, N, to drive it westward, coincides with that of the upper part of the current about the lower wire, also moving westward, so that the two coincide and assist each other.

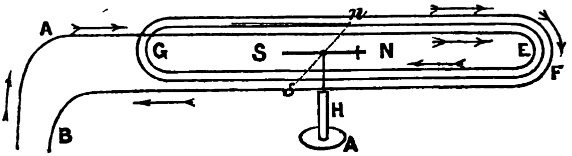

Fig. 282.

From all this it follows that if the wire at G is bent a second time, and carried back above the needle towards E, as shown here, and from thence again is bent round at F, the deflecting force is quadrupled, and so on, if the turns are farther multiplied. By this device of the coiling the wire around the needle, a very feeble voltaic current at the source is rendered so strong to deflect the needle, as to cause a distinct rattle or clink of it on an ivory pin, placed to limit its motion. And it explains why a voltaic battery in London of moderate strength, having a conducting wire of hundreds of miles in length, suffices to move magnetic needles suspended within such coils of wire, at the most distant as well as at various intermediate stations.

GALVANOMETERS.

981. *The Astatic Galvanometer.*—One of the first applications of Oersted's discovery was to the construction of a galvanometer or *current-measurer*, and one of the most delicate forms of these is what is known as the Astatic-needle Galvanometer. Fig. 283 represents a section of the instrument. It simply consists of an astatic pair of needles, N′ S′, S N, stiffly connected by twisting some fine copper or brass wire round the needles, and suspended by a fine silk thread—a fibre of unspun silk is preferable—so that the upper needle is outside the coil and visible while the other is inside the coil. The upper needle moves over a graduated circle of paper or pasteboard, so that the angle or degree of deviation of the magnetic needle from its natural position, which is made the zero of the graduation, can be exhibited. The ends of the coil wire are connected with the two binding screws, B, B′, into which are inserted the wires from the galvanic cell or battery whose strength it is desired to test.

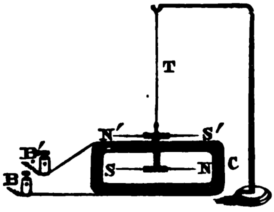

Fig. 283.

Such an instrument is exceedingly delicate, when the number of turns of wire is very great, and of course different degrees of sensibility in such instruments are desirable according to the intensity and nature of the electric current to be measured or detected, a delicate instrument being useless when the current is at all likely to be strong.

982. The *Reflecting Galvanometer of Sir William Thomson* is adapted for the detection of still more minute currents than the one we have just described. The exceedingly feeble current which survives the passage of the two thousand miles of cable between this country and America, would be quite insensible to any ordinary needle-galvanometer; and, but for the happy execution of the idea

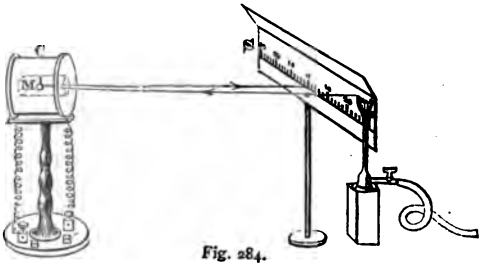

Fig. 284.

of the reflecting galvanometer, it is probable that the Atlantic Cable enterprise could not have been accomplished. With the help of the figure (fig. 284), the reader will require almost no description of this instrument It may be enough to say that a tiny needle attached to an extremely light glass mirror, the whole weighing only a grain and a half, hangs by a single filament of unspun silk within a coil of silk-covered copper wire, the inside diameter of the coil being only about three-eighths or half an inch. A beam of light from a gas or lamp flame, about a yard distant, passing through a small opening in a scale of cardboard, S, falls on the tiny mirror, M, and being reflected back, falls on the graduated part of the scale. The slightest motion of the mirror, M, will, by a well-known optical principle, be exhibited in greatly magnified motions of the spot of light upon the scale, S. The delicacy of such an instrument is perfectly marvellous.

For strong currents it is common to use a galvanometer, involving the very same principle, and consisting simply of a single strip of copper bent into the shape of a circle, with a short magnetic needle poised or delicately suspended at the centre of the circle. The strength of the current can be proved both mathematically and experimentally to be proportional to what is called the tangent of the angle of deviation of the needle, which may be read off either by reference to a graduated card, or by reflecting a beam of light, as in the Thomson galvanometer.

ELECTRO-DYNAMICS.

983. From the magnetic powers of the current already considered, we might naturally suppose that there must be some fundamental or simple laws of attraction and repulsion existing between straight currents in proximity. The precise exposition of these forms the division of this subject known as *electro-dynamics*, which would involve more mathematical details than are consistent with the plan of the present work. It may, however, be mentioned that currents passing along movable wires, or flexible metallic conductors of any sort, cause attraction or repulsion of these, according to their mutual directions. If the movable conductors be parallel, there is attraction when the currents flow in the same direction, and repulsion when they flow in opposite directions; if the currents are inclined to each other at an angle, there is attraction, if they both flow either towards or from the point of crossing, but repulsion if one flows from, and the other towards, this point.

The same laws of current action explain the mutual action of magnets and currents, when we adopt Ampere's view, that a magnet is a group of circular currents. It explains why two circular currents, such as currents flowing in a helix of copper-wire, will attract or repel each other exactly like magnetized bars. It explains why the current deflects the magnetic needle when the needle is movable, and it also explains why a bar-magnet attracts or repels a movable conductor, or why a movable conductor may rotate about a magnet when a current passes through it in one direction, and rotate in an opposite way when the current is reversed, or why a current may make a magnet rotate round its own axis. All these experiments may be easily performed in a variety of ways, and they are most interesting, theoretically, as supporting Ampere's hypothesis, and the fundamental laws of electro-dynamics.

ELECTRO-MAGNETIC ENGINES.

984. The discovery of the immense attractive power which can be developed instantaneously in soft iron by means of the galvanic current, and which can be as quickly stopped by the mere breaking of the galvanic circuit, led many to imagine that the glory of the invention of the steam-engine would speedily be dimmed by the invention of an *electro-motive engine*, which might be worked by the unseen power conveyed by a single wire from a distant battery. Many ingenious machines have indeed been devised, whereby a practically useful motive power might be thus obtained. They are either in the form of a reciprocating beam, whose ends are alternately attracted by two electro-magnets, the electric current being cut off from each magnet as soon as the beam is attracted by it—this alternating motion, as in the steam-engine, can, by a simple crank, be readily converted into a continuous rotatory one—or they are in the form of a series of radial arms of soft iron attached to a fly-wheel, with one or more electro-magnets, so disposed that a spring admits the current to pass when an arm is approaching the poles of the magnet, but the current is cut off the moment the arm is close to the magnet. The power of the latter is thus cut off, the momentum of the fly-wheel keeps up the motion until the spring again closes the circuit, and the next soft-iron arm is within attracting distance of the magnet.

It has been proposed to apply such motors to the driving of sewing-machines and small industries, and even to the propulsion of steamboats; but as the electro-motive power is derived from the oxidation of zinc in the cells of the battery, and the consumption of zinc is proportional to the work done by the battery, the high price of this metal is an insurmountable obstacle in the way of its use as an economic source of power. Its use would be probably fifty times more costly than the use of coal, though, doubtless, there are circumstances where, economy being of little object, such electro-motors would be more convenient than steam power. A much more practically useful application of electro-magnetism has been to *clock-controlling*, and to the construction of *electric chronoscopes*.

985. Amid the multitude of ingenious contrivances for applying electricity to the driving or regulating of clocks, the two most important and approved inventions have been those of Mr. Bain and Mr. Jones. The principle of Bain's electric clock, invented in 1840, may be thus described :—The bob of the pendulum is an electro-magnet or coil of insulated wire, with a short, hollow, soft-iron core, the extremities of the wire being connected with the two suspending springs of the pendulum. On each side of the bob is a permanent steel magnetic bar, with the two like poles facing each other, and so placed that the pendulum swings partly over each without touching. By a simple contrivance at the top of the pendulum, a current sent through the coil of the bob from a local battery, which causes attraction between one of the steel magnets and the face of the bob next it of opposite polarity, is reversed when the pendulum has reached the extremity of its swing ; repulsion between similar poles is the result, and the pendulum swings to the opposite side, until a break and reversal of the current once more reverse its motion. With this arrangement no driving weight or springs are required, and it was intended that a simple and cheap battery, consisting merely of a plate of zinc and a plate of copper buried in the damp earth, should suffice to keep up the oscillation of the pendulum and the motion of the clockwork. In practice, however, it has been found that such a driving power is unreliable for regularity, and not to be compared with the regularity of a falling weight or an unwinding spring.

Mr. Jones has improved very much on Bain's principle by using the current merely to *regulate* the motion of an ordinary clock. He attaches a pendulum with electric break and make arrangements quite the same as those of Mr. Bain, to a common clock driven by weights or by springs ; and he arranges a standard or governing clock, which is supposed to keep practically perfect time, and which may be situated at any distance, as in an astronomical observatory, so that at stated intervals the pendulum of the standard clock shall touch a spring and complete a battery circuit, which shall send a current through the distant electro-magnetic pendulum. If the latter be not in proper position when the electric wave passes through it, it receives an impulse which suffices to give it the needed acceleration or retardation, and keep it up to time. In this way one, or, in fact, any number of ordinary clocks may be made to possess all the regularity of the best astronomical clock. A clock of this kind is now in use in almost all the large towns of the kingdom for giving true time; and it produces the most satisfactory results.

986. The practically instantaneous passage of the electric current has also been applied to the determination of extremely short intervals of time, as, for instance, the time taken by a cannon ball in its passage between different stages of its course. The ball is made to break wires in its passage, and so interrupt electric circuits which govern the action of electro-magnets; these electro-magnets hold marking pointers against a cylinder turned by clock-work at a certain uniform rate, and the interval between the release of the pointers and the end of the indicating lines can thus be estimated with very great nicety. The times taken by a cannon ball to pass along the different parts of the bore of the cannon have even been found by this means, and the rate of acceleration of the expansive force produced by the explosion of gunpowder has in this way been estimated.

INDUCED ELECTRIC CURRENTS.

987. The illustrious Faraday, to whom the science of electricity owes so much, discovered, in 1830, that when a wire, whose ends were connected with a galvanometer, such as we have described in Art. 981, was brought near another wire through which a voltaic current was passing, there was a slight affection of the galvanometer needle. When the wires were separated there was again a slight indication, as of a momentary electric wave having passed through the closed galvanometer circuit. Further experiments regarding this phenomenon revealed that it was a case of current induction or electric influence at a distance, somewhat analogous to that already considered under the head of frictional electricity (Art. 939). Unlike the latter, however, this current induction was but momentary in its effects, taking place only when a galvanic circuit was brought near or removed from another metallic circuit, or when a galvanic circuit was broken or commenced in the presence of the other closed circuit, for it is evidently the same thing to break the galvanic circuit as to remove it to a distance.

It was shortly discovered that the induced or secondary current, as it was called, was opposite in direction to the inducing or primary current when the latter current was completed or brought near the former; and in the same direction as the primary when the latter was broken. Further, the nearer the two wires could be brought without metallic contact, the stronger was the induced current found to become; and the effect was very greatly intensified by winding the two wires, insulated by being overspun with silk, side by side on a reel or bobbin, as shown in fig. 285. Thus, if E F be the ends of the one wire, which are connected with a voltaic battery, and C D, the extremities of the second or secondary wire, it is found by rapidly making and breaking the current flowing through E F (as may be done by interposing a file in the circuit and drawing the end, E, across the teeth of the file) that a perfect stream of induced currents, alternately in opposite directions, flows between the points, C D, when placed near each other.

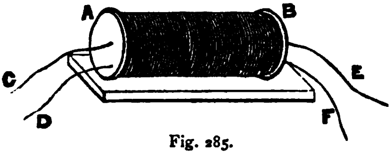

Fig. 285.

The induced electricity was found to partake more of the nature of high tension or frictional than of the massive current electricity. It will charge a Leyden jar very rapidly, will give most powerful shocks, and will produce all the beautiful luminous effects of the friction electrical machine. The best form of apparatus for producing these effects is that known as

Ruhmkorff's Induction Coil.

988. Figure 286 represents one of the most compact and convenient forms of this coil, as given by the original constructor himself. The essential parts of it are an iron core, or core of iron wires, bound firmly together, and seen protruding at the nearer end of the instrument, in the figure. On a bobbin with glass ends cemented upon it, and into which this core fits, is wound, first, a coil of thick insulated copper wire, one end of which is led to the binding screw, D, and the other to the brass support, E, which serves to convey the primary, or battery, or inducing current. Over this primary coil, and very carefully insulated from it by varnish, dissolved caoutchouc, gutta-percha, or paraffin, is a coil of *very fine* silk-covered copper wire, whose ends, K L, are connected with K′ and L′ as poles, these last being mounted on glass insulators, and the current passing between pointed brass wires as movable poles inserted in the binding screws, K′ L′. The only other parts which need be mentioned here are what is called the *commutator*, C, by means of which the entering current from the battery can be permanently turned off or on; and the break or hammer, H, by means of which the rapid interruptions of the primary current required for induction can be automatically made by the machine itself. It consists simply of a stiff brass spring connected with E, and armed with an iron head or hammer, H, which naturally rests on a pointed conductor below in metallic connection with the binding screw, S.

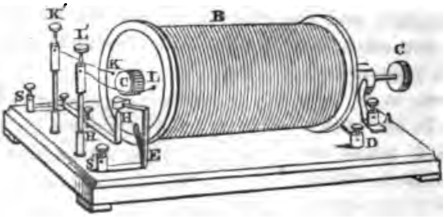

Fig. 286.

When, however, a wire from one pole of a battery is connected with the screw, D, and a wire from the other pole with S, and the commutator, C, is properly turned, the current passes through the coil and magnetizes the core; this attracts H, and the current thus interrupts itself. The magnetism ceases, H springs back to touch the conductor below, and allow the current to flow again: once more H is attracted and the current broken, and thus an incessant vibration of H is kept up, and consequent interruption of the inducing current. A succession of rapid induced or secondary currents pass between the secondary poles, if these are not too far apart; and, in this simple way, a most valuable and ready means of procuring electricity of high tension is provided.

Experiments with the Induction Coil.

989. A variety of most interesting experiments may be made by any person possessed of a moderate-sized coil, and two or three common battery cells. First, the physiological effects are very powerful, and care should be taken in tentative experiments; if one hand be connected with each of the poles, K′, L′, very violent shocks are felt; the electro-motive force or power to overcome resistance is very great in this secondary current; at every interruption of the break or hammer a powerful discharge passes through the body; and with a strong machine the nerves may be overpowered, so that, once having hold of the poles, a person may be unable to release his grasp.

If the two poles be connected with an apparatus for decomposing water, such as that described in Art. 966, it will be found that equal quantities of gas are liberated at each of the platinum poles, each consisting of a mixture of oxygen and hydrogen, the reason being that the induced currents are alternately in opposite directions.

A Leyden jar, or battery, may be very readily charged by connecting the outside coating with one of the poles, and placing the other (movable secondary) pole within a short distance of the knob of the jar. The intensity of the shock and spark is much increased by connecting the two poles, K′ and L′, with the opposite sides or conductors of a *condenser*. This may consist of sheets of tinfoil separated by sheets of oiled silk, the alternate sheets of foil being in connection, and placed in the base of the instrument. Provided with this, an induction coil may readily be made to pierce glass or fire gunpowder, or exhibit many beautiful phenomena of the electric light in rarefied air.

990. Fig. 287 will serve to illustrate a whole class of luminous experiments which are usually exhibited with the aid of the induction coil; and it may be here remarked that a small and inexpensive apparatus, such as, with a little care, any one may construct for himself, will suffice to show many of these luminous experiments on a scale suitable to a drawing-room party or a small lecture-room audience.

The battery may be a single Grove or Bunsen cell, P, covered with a tight-fitting lid to prevent escape of noxious fumes; the coil, C, built up of an iron-wire core, a few yards of thick primary wire, and say a pound of very fine silk-covered copper wire; if provided with a condenser all the better. The receptacle of the electric discharges is what is known as a *Geissler tube*, being a variously-coloured glass tube or vessel, containing rarefied air, or a small quantity of any single gas, such as oxygen, nitrogen, hydrogen, &c., and hermetically sealed. They were first constructed by a German optician, Geissler of Bonn; and Geissler tubes, often of very beautiful design, and of German manufacture, are now common articles of sale in the philosophical instrument shops. Two platinum wires, C, C', are hermetically sealed into the ends of such a tube, and serve as the poles for electric transmission; on connecting these by means of two silk-covered wires with the poles of the induction coil, a most gorgeous effect is produced in the dark. The electric light flitting inside the tube forcibly reminds one of the aurora; while it is usually also stratified or made up of alternately dark and luminous bands, the cause of the alternation being most probably due to the interruptions of the break. A magnificent effect is produced if the glass of the tube be in whole or in part tinted with uranium, or filled with a solution of sulphate of quinine; it then is lighted up with a pale fluorescence (Art. 899), than which there is no prettier sight in experimental science.

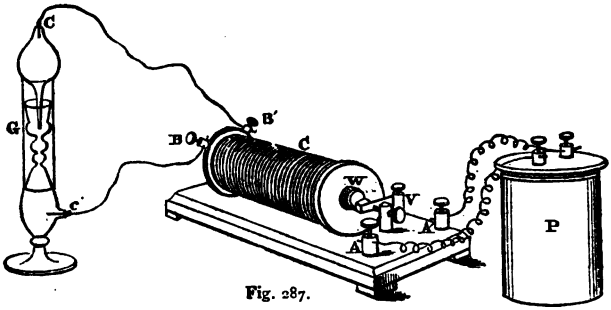

Fig. 287.

The interesting nature of the machine, and the numerous experiments that may be performed with it, may be inferred from the fact that a whole volume of 400 pages is published by M. Ruhmkorff, descriptive of its construction and applications.

MAGNETO-ELECTRIC INDUCTION.

991. The discovery of current-induction, made by Faraday in 1830, to which we have already referred, was but the beginning of a splendid career of discovery by that illustrious philosopher. Reasoning from the fact that the inducing effect of a coil was increased by the proximity of soft iron, he found that when the soft-iron core was rendered temporarily magnetic by a common steel magnet, the induced currents were still produced. Thus by moving a magnet in the presence of an insulated coil with an iron core, or by moving the coil while the magnet remained stationary, or even by moving the coil with reference to the magnetic axis of the earth, a stream of momentary induced currents was generated.

The mutual relations of the current and magnetic force in these very complex phenomena were seized by the clear intellect of Faraday, and included in a comprehensive general law, which served to unravel much apparent inconsistency and confusion in the phenomena of magneto-electric induction. These discoveries were embodied in a magneto-electric machine constructed by Pixii, of Paris, in 1833, in which a strong horse-shoe steel magnet, revolving in front of two insulated coils of wire, induced currents in the coils. The machine was shortly improved upon by Saxton, who fixed the magnet and made the lighter coils revolve in front of the poles. Saxton's machine was still further improved by Clarke, who gave the machine the arrangement which is retained in the smaller forms now in common use for medical and other purposes, the essential parts of which are represented in the annexed figure.

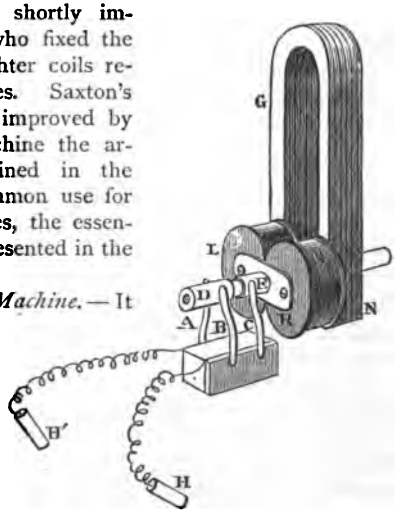

Fig. 288.

992. *Magneto-electric Machine.*—It consists simply of a large horse-shoe magnet, or bundle of magnets, placed upright or laid horizontally, as may be most suitable (fig. 288). In front of the two poles, two coils, or bobbins, of silk-covered copper wire, with soft-iron cores, are turned on the axle, D E, by means of a multiplying wheel arrangement not shown here. The commutator, or current-changer, D E, in fig. 288, is the only intricate part of the machine, and is the part on which the efficiency of the whole depends. To understand the action of the commutator, we must consider the law of induction of the magnet on the coils.

The two soft-iron cores of the coils are connected by a cross-piece of soft iron, so that they form really a bent horse-shoe magnet or armature to the large magnet. In the core opposite the north pole of the large magnet south magnetism will be induced (Art. 971), and in the other core north magnetism. North magnetism in the core will induce a current in the coil in one direction, and south magnetism a current in the opposite direction. Now, as the two coils are connected and are wound in opposite directions round the two cores, it is evident that the inducing effects of the two poles of the magnet, when the armature coils are in the position represented in the figure, will coincide, and their two currents will unite and flow through the completed circuit in the same direction. As the coils turn round from the position in the figure to the reverse position, we must remember that the inducing effect of a withdrawal of the coil from one pole is the same as that of an approach to an opposite pole: thus the inducing effect in *each* coil is in one and the same direction until the right coil, R, arrives opposite the south pole of the large magnet, and the left coil, L, comes opposite the north pole; when the whole conditions and the direction of the current are reversed. But for the commutator, then, the current would be, during one half of a revolution of the armature, in one direction, and during the next half, in the opposite direction.

The commutating arrangement, by which the current is made to flow continuously in the same direction, may be thus explained: Two half rings of brass are fixed on the axle of the armature, so as to be insulated from each other, the free end of the wire from the coil, R, being connected with one half ring, and the free end of the wire from the coil, L, being connected with the other. Springs—with which the wires leading to the sensitive indicator of the current, whether an animal body or a galvanometer, are connected—press on these half rings in such a way that when the direction of the induced currents is being reversed—that is to say, as the armature is moving from the line of the inducing poles—each spring is passing from the one half ring to the other.

With such a machine water may be readily decomposed, platinum wire made red-hot, a piece of iron or steel magnetized, and very powerful shocks may be obtained.

Compound machines on the same principle have been devised, by means of which surprising electric effects are produced. To give a detailed account of even the most important of these, interesting as they are, is beyond the scope of the present work. We shall merely state a few of the more striking facts connected with these curious machines.

In a large machine for producing the electric light, constructed by Holmes, of London, as many as eighty-eight coils of wire are placed round the circumference of a wheel, which is turned by a steam-engine within a series of inducing steel magnets placed in a concentric circle round about.

993. *Wilde's Machine.*—More interesting is the invention of Mr. Wilde, of Manchester, who conceived the ingenious plan of using the induced current to act upon an inducing electro-magnet, thus strengthening its magnetism and its inducing power. Its principle may be inferred from fig. 289, which represents the upper part of it, the lower portion being almost an exact reproduction of this part on a much larger scale.

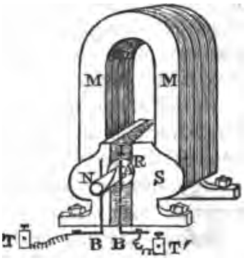

Fig. 289.

This part consists of a series of steel horse-shoe magnets, forming a sort of bridge, within whose arch turns a long coil or armature, known as Siemens' armature, in which the insulated wire is wound *lengthwise*, instead of crosswise, as in the ordinary form of coil. Very powerful currents are induced in this form of armature by reason of the proximity of the coil to the poles of the magnet. By means of a commutator on the axle of the armature, the current is sent in one uniform direction to the binding screws, T, T′, whence it passes to the coils of a huge electro-magnet, over which this primary miniature machine stands. Between the soft-iron poles of this large electro-magnet is turned, by the same motory power as that which turns the upper armature, a much larger Siemens' armature, in which vastly more powerful electric currents are induced.

Mr. Wilde has even carried his principle a step farther, and used this second induced current to excite a second electro-magnet still more powerful than the first, and by means of this triple arrangement electric effects of unexampled intensity have been obtained With such a machine, driven by a 15-horse power engine, the armature revolving at the rate of 1500 times per minute, the inventor was enabled to melt a rod of platinum two feet long, a quarter-inch bar of iron fifteen inches long, and seven feet of No. 16 iron wire, and to heat red-hot twenty-one feet of iron wire. The luminous effects were perhaps the most surprising. When the current passed between thick sticks of gas-carbon (½-inch square), placed on the top of a lofty building, the light rivalled that of the sun in splendour; shadows were cast from the flames of street lamps a quarter of a mile distant, and photographs might readily be taken with the power of its chemical or actinic rays.

994. Still further simplifications and improvements of Wilde's principle have been embodied by Siemens, Wheatstone, and Ladd, in elegant and compact machines of such wonderful power, that care must be taken not to work them too long or too violently, otherwise the wire of the inducing coils may get so hot as to produce their own destruction.

In all these machines we have exemplified the conversion of mechanical power or energy into electrical energy; rather, in the case of the larger machines, we have the transformation of heat-energy, first into mechanical, and of the latter into electrical energy, together with a fractional restoration into heat energy.

Before passing on to describe the most important of all the applications of electricity, *viz.*, the Electric Telegraph, we shall briefly notice one other means of generating electrical currents, whereby heat is converted directly into electricity without any intermediate mechanical transformation.

THERMO-ELECTRICITY

995. Is the name by which these heat-born electric currents are designated.

The elementary fact in connection with this subject is, that if any two different metals are included in a closed galvanic circuit, an electric current is set up whenever the junction of the two different metals is heated; and the current flows in a direction which is quite definite for each pair of metals, but is different for the same metal when differently paired. Thus, for instance, if a piece of iron wire or rod be connected with the copper wires from a galvanometer, G, and we heat with a spirit lamp, or a lucifer match, the junction, B, of the two metals, the

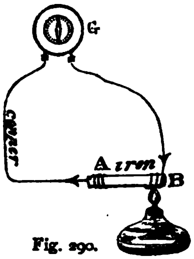

Fig. 290.

galvanometer needle will be deflected so as to indicate the flow of an electric current in the direction shown by the arrow head in the figure 290; but if we apply the heat at the opposite end, A, the current is reversed, so as still to flow *from the copper to the iron at the heated junction.* Had we, however, connected a platinum wire, instead of an iron one, between the ends, A B, of the copper wires, we should have found that at the heated junction the current would have flowed *from the platinum to the copper.*

Copper is thus said to be thermo-electrically positive with respect to iron, but thermo-electrically negative with reference to platinum. By such experiments, most carefully performed, it has been found that, just as the metals can be arranged in an electro-chemical order (Art. 962) indicating the direction of the current when any two are connected as a galvanic pair, so they may be arranged in a thermo-electric order indicating the direction of the current produced by heating a junction of any two of them. According to Becquerel, this order is

Bismuth, platinum, lead, tin, copper, silver, zinc, iron, antimony;

The direction of the current at a junction of any pair being the same as the order in which the two are named in the line; and the farther apart they are in the line, the stronger will be the electromotive force of the thermo-electric current produced.

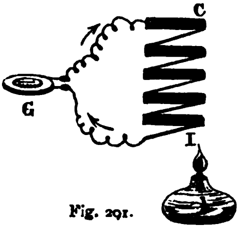

Fig. 291.

996. By connecting a number of thermo-electric pairs, as in fig. 291, we may form a thermo-electric battery, which will give a constant current so long as we keep the front face of junctions at a higher temperature than the back face, the resulting current being from the last iron to the first copper. Many attempts have been made to replace the galvanic battery by such a cleanly source of electricity as this arrangement would be; but the currents are so much less energetic than those resulting from chemical action, that no important practical results have as yet followed in this direction.

997. *The Thermopile.*—The most important use to which the thermo-battery has been put, is the detection of minute differences of temperature, for which purpose it was first used by Melloni in his experiments on radiant heat. A large number of antimony-bismuth, or copper-iron, pairs are arranged in a compact form as in fig. 292, each pair and layer being carefully insulated by varnished paper. The whole is enclosed in a tube, A B (fig. 292), one face of the junctions being exposed at each end of the tube. Such an instrument is extremely sensitive to difference of temperature at the two faces; connected with a sensitive astatic galvanometer, or the still more sensitive reflecting galvanometer of Sir William Thomson (Art. 983), it will indicate the approach of the hand to either face by an instant deflection of the needle; and a momentary touch with the warm finger may swing the needle round half the face of the dial or more. If a piece of ice, or a tumbler of cold water, be brought near the face, there will be a turning of the needle in the opposite direction. Thus the mere direction of the needle indicates whether any face is being heated or chilled: only it must be remembered that the heating of one face has the same effect as the chilling of the opposite face.

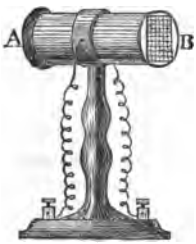

Fig. 292.

Very delicately constructed thermopiles have been used to detect the heat transmitted from the moon and the stars to this earth; degrees of temperature far too minute for the indication of any ordinary thermometer.*

THE ELECTRIC TELEGRAPH.

998. Having described various methods by which the electric current may be produced, it still remains for us to give a general idea of the principles of the most wonderful, and by far the most useful, of the manifold applications of this unseen power, *viz.*, the *electric telegraph.* The veriest child of the present day is familiar with the name of the electric telegraph, which sounded so strange and mysterious to all but the philosophic few within a comparatively recent period. To enumerate all the uses of this admirable invention, would be to catalogue the multitudinous pursuits of mankind; for there is no art or industry, no profession, or situation in modern life, in which the assistance of this wingless messenger is not summoned to perform for man the duty of the fabled Mercury. Information of importance to individuals, or to the public, is sent from any part of the world to any other, and questions are asked and answers returned within a few minutes. When the signs of coming storms, now much better understood than formerly, are anywhere observed, a telegraphic notice, which travels a thousand times faster than any storm, can be sent to places in the direction of the storm's progress, so that useful precautions may be taken. In sea-ports, ship-captains, so warned, can delay sailing until the danger has passed. If telegraphs on railways did not constantly send information along the lines of the arrival and departure of trains, not half the present traffic on the lines could be safely carried on. When, at the Observatory of Greenwich, the clock marks the instant of noon, or any other time, the fact, through a telegraph connected with the clock, is declared at many other important stations, as Liverpool, York, Glasgow, Edinburgh, where by the dropping of a ball obeying the telegraph, in a conspicuous place, or the firing of a gun, the information is widely spread. A gun fired on the Castle Hill of Edinburgh by an electric wire, nearly a mile in length, stretched high in the air from the Observatory, is heard for many miles around. Shipmasters about to sail, hearing such a report, can set their chronometers exactly to Greenwich time; and clocks and watches over the country, which maintain order in the whole business of society, may thus be regulated.

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* One of these instruments exhibited by Faraday at the Royal Institution was so delicate that the warmth of the body of a fly in walking over it was sufficient to produce a visible change.

The Construction of the Telegraph.

999. The invention of the galvanic battery, the discovery of the deflection of a magnetic needle by the current, and the discovery of the magnetization of soft iron by the current, were the three great steps in the history of the electric telegraph. As early as 1830 it had been suggested that Oersted's discovery might be employed for the transmission of signals to a distance; and a model telegraph, consisting of some thirty pairs of conducting wires and as many indicating needles, was exhibited by Professor Ritchie at the Royal Institution of Great Britain. Much about the same time a similar form of telegraph was proposed by Schilling, in Prussia; but the great complexity and costliness of such a system rendered these inventions practically useless.

The first simplification was effected by making a single return wire serve as a common completer of the circuit for all the thirty wires and needles; and one form of instrument consisted of a set of keys like those of a pianoforte, each key corresponding to and connected with one of the wires, with its needle placed at the distant station. The zinc pole of the battery was connected with the return or common wire, and the copper pole was joined to a plate of metal or a trough of mercury, extending beneath all the keys; thus, on depressing any key, a current passed through the corresponding wire and deflected at the distant station, a needle which bore the same letter as the transmitting key. Any message might thus be spelled out and readily interpreted at any distance; the sole fault was the clumsiness and costliness of the transmitting system of wires.

In 1837 a remarkable simplification was introduced and patented by Messrs. Cooke and Wheatstone, to the latter of whom the world is indebted for many other novelties of high value and great ingenuity, among which are the *stereoscope*, the *concertina*, and *symphonion*, which delight the eye and the ear.

The novelty of this invention consisted (i.) in using the two directions, to which the needle might be swung by changing the current, as separate symbols, and so reducing the number of indicating needles required; (ii.) in using the current to ring an alarum bell at the distant station before sending a message; and (iii.) in connecting two sets of batteries and instruments at the two communicating stations, so as to make the power of communication reciprocal.

To recount the many trials and experiments of these and other investigators, by which improvements were one by one effected, and even to name the contrivances suggested for speedy telegraphic purposes, would occupy a volume in itself. We shall therefore merely sketch the general features of the final results to which all these investigations, so enthusiastically prosecuted, have led.

1000. Every telegraphic system must of necessity comprise (*a*) the current generator, or battery, (*b*) the conducting or circuit wire, by which the current passes to the distant station; (*c*) the transmitting apparatus by which the signals are to be sent; and (*d*) the receiving or indicating apparatus by which the signals may be interpreted.

With regard to the first of these, the battery, there is nothing special required farther than a steady-going battery of moderate strength or electro-motive force. Daniell's or Leclanche's battery is particularly suitable for telegraphic purposes.

The conducting wire used for land-telegraphs is generally galvanized or zinc-coated iron wire, carried on high poles, and insulated either by means of glass or porcelain insulators of a cup-shape.

Underground wires coated with gutta percha, or other insulator, were first employed and are still employed in large towns, where air-lines would have their insulation endangered. A very valuable discovery was made by Steinheil in 1837; when experimenting whether the iron rails of a railway would serve the purpose of a return wire to complete the circuit, he found that the earth itself might be made to serve the purpose, and the expense of wire was thus at once reduced to one half. The figure (293) will show the arrangement usually adopted for this purpose. It represents two stations connected by a line of telegraph. C Z is the battery at the one end, C′ Z′ at the other; G, G′ are the galvanometers, to be presently referred to, by means of which signals can be exchanged; H and H′ are two handles, by means of which either the zinc pole or the copper pole of the battery can be connected with the galvanometer wire and the line wire, while the copper or the zinc pole is at the same moment connected with the wire, which leads to a large metal plate buried in the earth. By turning the handle, H, for instance, to the left hand, the wire from the copper pole of the battery is connected with the end of the galvanometer wire, the other end of which is connected with the line wire, while at the same time the zinc wire of the battery is put in metallic communication with the earth-plate, P′. Practically the effect is the same as if the current flowed from C through G along the *line wire* to the distant G′, thence to the distant earth-plate P′, thence through the earth to P, and back to the battery at Z. By turning the handle to the right, a current flows through the whole circuit, as it may be called, in the reverse direction, and the distant galvanometer, G, turns to the opposite hand.

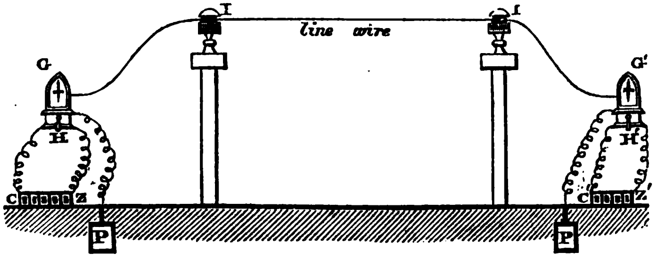

Fig. 293.

The real theoretical explanation of the case now adopted, is to say that the earth drains off the opposite electricities, which would otherwise accumulate at the terminals, the effect being thus precisely the same as if both plates were connected directly, the current being in reality one uninterrupted succession of discharges of the positive and negative electricities, produced at the copper and zinc poles of the battery.

1001. The *sending apparatus*, or *transmitting key*, by which the signals are given, is in its simplest form merely a contrivance for making and breaking contact between the battery and the line; and, in the older form of the instrument, it is simply a commutator for changing the connections between the battery poles and the line wire. They will be described incidentally in explaining the indicating contrivances.

1002. Fig. 294 will give an idea of the principle of the *single needle telegraph* of Cooke and Wheatstone, which is still extensively used in this country, though not very much anywhere else. It consists of an upright galvanometer with an astatic pair of needles, the motions of the outside one to right or left constituting the signals, one end of the galvanometer wire leading to the connection, N, the other to the line wire. R is the commutator, or current changer, which has two insulated metal plates in permanent connection with the two poles of the exciting battery, C Z, and so arranged that a slight motion to one side, say the left, of the handle, H, puts one of these plates and the corresponding pole of the battery in connection with the earth through P, while it puts the other and its battery pole simultaneously in connection with the line through N.

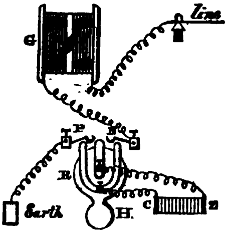

Fig. 294.

Thus a negative electric wave passes along the line, and deflects both the local needle and the distant needle to the same side. A slight motion to the right reverses the connection, and deflects both needles to the opposite hand.

Out of a combination of these two motions to right and left, an alphabet is agreed upon, those letters getting the simplest signals which occur most frequently in ordinary language. Thus, for instance, as E and T are most frequently used, one swing of the needle to the left stands for the letter E, and one to the right for letter T: A is one left, one right; B is one right and three left; C right left, right left, and so on.

The actual form of the commutator in use is cylindrical, but the form shown in the figure is identical in principle, and is frequently used for commutating purposes on the Continent.

1003. Of this single needle, or of any needle telegraph, the great disadvantage in practical use is the transient nature of the signals; and it is now completely superseded by the admirable self-recording instrument invented by Professor Morse, of America, about the year 1837. Without giving the mechanical minutiæ, the adjoining figure (fig. 295) will enable us to explain the general features of the Morse system.

The signalling apparatus is a mere make and break brass key, B, which is connected permanently with the line wire, and which may be connected with the zinc or copper pole of the local battery, according to whichever end is depressed. When not in action, it is held by a spring in the position represented in the figure, so that the line-wire is always in connection with the earth-plate.

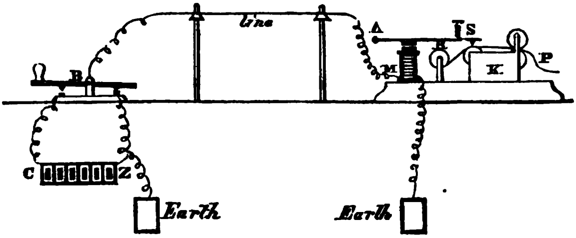

Fig. 295.

The Morse, M, seen at the other end of the line, consists of an electro-magnet, M, one end of whose coil is connected to the line, the other to the "earth:" a brass armature, A S, with an iron piece opposite the magnet, and movable about a hinge at A, carries a pointed style or pencil, S, at the other end. It is obvious, then, that so long as the key, B, at the other end is depressed, M is magnetized, and the armature, A S, attracted; thus, if the pointer, S, press on a strip of paper, B, coiled on a bobbin, R, and unwound when desired by means of clockwork in K, it is evident that a momentary magnetization of M, caused by a momentary depression of the key, B, will mark merely a dot, while a longer-continued depression will mark a line on the paper. In this way a succession of dots and dashes may be transmitted with great rapidity; and, an alphabet being agreed on, composed of combinations of dots and dashes, Professor

Morse has in this way solved the problem of conveying a permanent message to any distance by means of the electric current.

The Morse telegraphic alphabet, which is now adopted by all nations, represents the most frequently occurring letters by the simplest symbols; a great number of arbitrary signals and abbreviations being adopted by experienced practical telegraphists. It is as follows :—

A	B	C	D	E	F	G
·—	—···	—·—·	—··	·	··—·	——·
H	I	J	K	L	M	N
····	··	·———	—·—	·—··	——	—·
O	P	Q	R	S	T	U
———	·——·	——·—	·—·	···	—	··—
	V	W	X	Y	Z	
	···—	·——	—··—	—·——	——··	

Besides these, there is an ingenious system of dot-and-dash symbols for numbers, as well as for the names of all different telegraphic stations.

1004. The *Relay*, represented in fig. 296, is a remarkably ingenious though simple contrivance, by which the feeble electric current which survives the leakages of a long journey, and is unable to impress its message directly, can summon to its assistance a local battery at the distant station, and so accomplish its mission. It consists of a very fine coil of silk-covered wire, R, through which the line-current passes to the earth. This current would be too feeble to act upon the Morse directly, but affects the sensitive *Relay* so as to attract a light brass armature, A T, with the axle, X, of which the copper pole of a local battery is connected, while the zinc pole is connected to the coil of the Morse instrument, M; a metal pin in

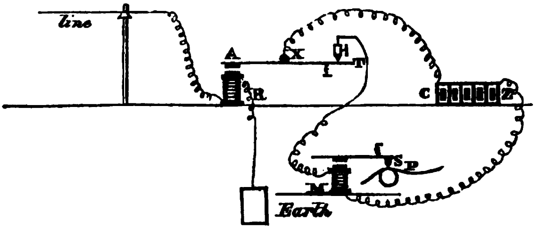

Fig. 296.

communication with the other end of the Morse coil is so placed that the armature, A X T, bears against it whenever the end, A, of the latter is attracted. Thus every attraction of the armature of the relay will allow a local electric wave of short or long duration to pass through the Morse; and the result imprinted by S on the paper, P, will be exactly the same as if the line current had done the work directly. In the earliest Morse instruments, the marking style, S, was a pencil, but it required so often to be sharpened that this was given up for a simple metal point which indented the message in the paper. Modern instruments, however, actually mark the message on the paper in ink, and with greater accuracy and ease than it could be indented, an inking roller or wheel, placed at the end of the lever, replacing the points. Sometimes the recording apparatus of the Morse is removed altogether, and the message is read off by the clerk by the mere sound. Its advantage over the old needle system, which it resembles in being non-recording, is that the ear is a more reliable interpreter in such cases than the eye, and the labour is very much less.

Besides recording the message, or, instead of recording the message, at the distant station, the Morse there may be turned into an automatic re-transmitter of the message to a second station farther on. In this way telegraph messages may be sent, without the labour of re-transmission, to almost any distance by means of *relays*. With delicate instruments of this class, messages are transmitted by the Messrs. Siemens from London to Teheran, a distance of nearly 4000 miles, without any re-transmission, five relays being interposed in the circuit.*

It is beyond the scope of the present work to describe the various forms of telegraphic apparatus which have been invented in recent years; there seems, indeed, to be almost no limit to the possible accomplishments of telegraphy. Wheatstone and Breguet have invented dial or clock-face telegraphs, so called from the letters of the alphabet being marked round a dial; and, incredible as it might have appeared to the world of the last century, any untrained person may with one of these instruments actually spell or point out, letter by letter, his communication to a friend at any distance. Wheatstone's "Universal Telegraph" is of this description, and is now a common piece of office furniture in our larger mercantile houses and hotels. More wonderful still is the *type-printer*, invented by Hughes, of America, in 1859. It actually prints the message in Roman characters, on a long strip of paper, and is a most marvellous piece of ingenuity.

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* See 'Electricity and Magnetism,' by Professor Jenkin, p. 309:—

The following experiment will serve as a singular illustration of the velocity of the electric impulse as transmitted through metallic wires. On New Year's Day, 1845, a few seconds after the year had commenced, a message travelled from Paddington to Slough apparently 'in less than no time,' for it actually reached its destination in the year 1844. The difference of longitude makes the point of midnight at Slough a little after that at Paddington, so that a given instant which was after midnight at one station was before midnight at the other.

Lastly, by an invention of Casselli, named by him the *Pantelegraph*, a person writing a despatch, or even drawing a sketch, at one place, may have a fac-simile of his handiwork reproduced the same instant by telegraph at a distance of a hundred miles or more.

Submarine Telegraphs.

1005. Surprising as are these achievements of telegraphy, they are rather triumphs of mechanics than of this science, for it is simply the electro-magnetic property of the current that is in every instance employed. The purely electrical triumphs of the last quarter of a century, accomplished by a thorough knowledge of the laws of this subtle agency, are no less important, though perhaps less striking. Until 1850, the problem of bridging the sea by telegraph had been unsolved; in that year the first ocean telegraph line between Dover and Calais was successfully laid; and it was considered a sufficient encouragement, though this cable lasted but a single day, to attack the problem with greater determination than ever. Every one now knows the success which has attended the indefatigable labours of electricians in connection with this problem. There are now many hundreds of telegraph cables, throughout the civilized world; and if joined end to end they would girdle the globe several times. The great feat of ocean telegraphy, the uniting of Europe and America, which, after many extraordinary difficulties and disappointments, was at last successfully accomplished, deserves special notice.

1006. *The Atlantic Telegraph.*—In 1857 the first attempt was made to lay an Atlantic telegraph from Valentia in Ireland, to Newfoundland; but after some 330 miles of cable had been submerged, it snapped. In the summer of the following year this cable was spliced, and, after three repeated failures by breaking of the cable, the operation was at last successful, and Newfoundland was in momentary connection with Ireland. Several messages were sent; the problem was solved; and, although the cable became useless in a few days, the failure was doubtless due to insufficient care in its manufacture.

After some years, the necessary funds for a renewal of the undertaking had been provided; a much better knowledge of the principles of submarine telegraphy had been acquired; and the *Great Eastern* was chartered for the undertaking. On the 23rd of July, 1865, a Company commenced laying it from Valentia; they had paid out 1186 miles of cable, and were within 606 miles of Newfoundland, when it chafed against the bows of the *Great Eastern*, and broke in a depth of 2000 fathoms of ocean. Owing to the want of proper grappling apparatus, they failed to recover the lost cable. Next year, again, the *Great Eastern* started from Valentia with a new cable, which was laid without a hitch. Not only so, but a search for the lost cable of the former year resulted in success, and by the 8th of September, the two cables were in working order between the Old and the New World.

To show the remarkable perfection of the insulation of the two cables, Mr. Latimer Clark joined the ends of their two conducting wires in Newfoundland so as to form an immense circuit of 3700 miles, and then, by means of a battery formed of a lady's thimble, a strip of zinc, and some acid, he succeeded in signalling through the whole of this enormous length of wire.

The Atlantic cables consist of (1), a central conducting strand oı seven copper wires; (2), an insulating coating of gutta-percha over this; (3), a layer of five strands of hemp, soaked in a tarry compound to protect this insulation from injury; and (4), an outside protecting sheath of eighteen strands of iron wire, the whole being slightly over an inch in diameter, and weighing three quarters of a ton per nautical mile.

Since the completion of the English Atlantic cable in 1866, a French cable has been laid from Brest to the Island of St. Pierre, which very much resembles the former in construction, being, however, of a somewhat lighter make.

The indicating apparatus used with the Atlantic telegraph is a Thomson's reflecting galvanometer (Art. 983), which instrument alone is sensitive enough for the purpose. Right and left deflections of the spot of light correspond to dots and dashes in the Morse alphabet; and but for this wondrously delicate contrivance, it is questionable whether the Atlantic cable, when laid, would have proved practically successful.

It is remarkable that short signals entering this cable, owing to the retarding effects of induction, ooze out at the other end as long signals, and but for the laborious investigations of the best electricians of the day, this difficulty alone would have made the cable anything but a commercial success, as the transmission of a message would have occupied too long a time. In order to give some idea of how these difficulties have been overcome, it may be stated that it has been ascertained that for about one-third of a second after an electric wave or current has set out from Valentia, there is no sensible effect in Newfoundland; after two-fifths of a second the effect is very feeble, only about seven per cent. of the maximum effect which is perceived after the lapse of three seconds. If no means had existed of overcoming the delay consequent on this drawling out of the current, it would have taken about two minutes to transmit an average word to America; whereas a speed of about fifteen words a minute has been actually attained—a speed perfectly marvellous when the difficulties are fully appreciated.

1007. *Duplex Telegraphy.*—Further improvements, by the study of the laws of electricity, have been quite recently effected in telegraphy, whereby, a single wire may be made to carry simultaneously two or more messages in the same or different directions, without any interference or confusion resulting. The explanation of the principles, however, on which these operations are based, is beyond the limits of such a work as the present; it may be readily obtained in the technical manuals on the subject which are now easily accessible.

1008. In connection with the subject of telegraphy, and as exhibiting the world which it has discovered for human ingenuity to conquer, we may mention a rather remarkable invention recently made by a Spanish gentleman.

Its object is to place a series of stations—such as all the houses in a town or district—in communication with a head central office, so that on any sudden emergency a message might be despatched giving the locality of the station requiring assistance, and the nature of such assistance. Without entering into technical details we may say, that, in the case of ordinary telegraphic stations mutually connected, the power of sending a message from one station may be interfered with by an intermediate station, and much delay occasioned thereby. By this newly-invented arrangement, however, every station may secure for itself a hearing at head-quarters until its message is completed, when the next in order of time may obtain an audience in its turn. The essence of the system lies in employing two separate wires with each of which each station has connection. The one wire is for sending notice to the central station, which it does by transmitting a current, to throw the central "Morse" into connection with the sending, or line-wire, and by an ingenious contrivance completing the sending circuit so as to allow of the message being sent only from the particular station which "*started*" the signal. Nobody can send a message until he has first signalled along the starting-wire; and then no one can interfere with the delivery of the message until it is complete. As soon, however, as the message is complete, the Morse, by an automatic arrangement, returns to its first connection with the starting-wire, so as to be at the beck of the next caller. It appears very suitable for hotels, hospitals, and large offices, where telegraphic communication with a single head office is in operation.

1009. This account of the electric telegraph would be incomplete without some illustrations of its extraordinary effect on time. It appears on some occasions to overthrow all our ordinary notions of time, as measured by the sun. One instance of this has been already given in a note at page 765, and the two following instances furnish a wonderful proof of the velocity with which the electric current may be made to pass by land and water from one station to another however remote:—

On a Thursday night at 9.8 P.M. a London mercantile firm received a message which had been sent *viâ* Teheran from Kurrachee, India, on Friday morning at 12.43 A.M. The message was therefore received in London *the day before* it was sent from India. The time actually occupied by the message in transmission was fifty minutes. The sun would require four hours and twenty-six minutes to travel the same distance, and as the message was sent soon after midnight, the extraordinary result was produced of its arriving at its destination on the previous evening.

On another occasion, a direct communication was made by uniting the telegraph wires between Valentia, in Ireland, and San Francisco, in California. A message was sent from Valentia at 7.21 A.M. on February 1, and after traversing the bed of the North Atlantic and the whole continent of North America, the acknowledgment of it was received in Ireland at 7.23 A.M. The San

Francisco time when the message arrived there was 11.20 P.M. of January 31—this place being eight hours to the west or earlier than our time. The distance traversed by the message going and coming was 14,000 miles in two minutes. This of course included the time required for working the telegraph at each station.

In closing our short account of the phenomena of this most wonderful of all natural agents, it is curious to reflect that, notwithstanding all the uses and facts of its wonderful workings which have been discovered, its real nature remains as mysteriously elusive as ever. Whether it is a fluid of spiritual fineness, using matter as its vehicle in its rapid course, or whether it is a particular manifestation of that same ethereal medium which manifests itself otherwise as light and heat, or whether it is a purely molecular affection of grosser matter, philosophers have not been able to discover.

SOLAR TELEGRAPHY.

1010. The reflected light of the sun has been used for the purposes of telegraphic communication, and so far as the exchange of signals is concerned, it has been perfectly successful. When the sun's light falls at a certain angle upon a sheet of glass, it is powerfully reflected (Art. 881, p. 650), and if there is sufficient elevation and a clear atmosphere, the reflection may be plainly seen at a distance of several miles. Thus the glass roof of the Crystal Palace, at Norwood, may be seen by reflected light, at several miles' distance, when the palace itself is only dimly visible.

Captain Drummond, the inventor of the lime-light, constructed an apparatus for signalling by flashing the sun's rays by a reflector. He gave to it the name of *Heliostat.* It consisted of an adjustable mirror as a reflector, worked in connection with a combination of telescopes. In an improved form it is now used in trigonometrical surveys, and, by its aid, triangles, having sides above 100 miles in length, have been formed in Great Britain. Among these may be mentioned that formed by Sca Fell in Cumberland, Donard in Ireland, and Snowdon in Wales, the sides of which are respectively 111, 108, and 102 miles in length.

The use of this heliostat in flashing the sun's rays, did no more than convey an arbitrary set of signals. Mr. Mance has lately so improved this method of signalling, as to enable observers at two remote stations to converse with each other. The instrument is called the Mance heliograph, or the sun-telegraph. It consists in the first place, of a light tripod stand, about four feet long when folded up for transport. On this tripod is screwed a circular mirror, varying in diameter according to the purpose for which the instrument is designed; that is, whether for field or fixed observations. If for the former purpose, the mirror is about four inches in diameter; while, if for the latter, it is about nine inches. The mirror is hung in a frame so as to revolve about a horizontal axis, and it is adjusted to the required angle of incidence with the sun by means of a telescopic connecting rod, having a screw adjustment, the top end being attached to the upper edge of the mirror at the back. The horizontal circular traverse of the instrument is obtained by means of a tangent screw-gearing into a small horizontal worm-wheel, with the centre of which the mirror is connected. By means of the tangent screw and the vertical screwed rod, the rays of the sun can be made to fall upon any given point with the utmost precision. The vertical rod behind the mirror is pivoted at the bottom to a lever, the fulcrum of which is on the horizontal worm-wheel, the lever constantly pressing against the lower end of the rod by means of a spring which is placed under it. It will thus be seen that when the rod is depressed, it will depress the top edge of the mirror and draw it slightly backwards, the bottom edge being at the same time slightly raised and thrown forwards. In adjusting the instrument in order to commence signalling, the rays are directed to a point slightly below the distant observer's level, but upon depressing the connecting rod—for which purpose there is a small finger-piece attached to it—the flash is raised to the level of the observer, and he sees it. If now the lengths of these flashes be varied and grouped they can be made to represent letters, and so words composing messages can be spelt out.

In adjusting the instrument for use a light wooden rod, having two brass sliding sights upon it, is employed. This is set up in the ground in front of the instrument, and the operator looks through a small space in the centre of the mirror, from which the quicksilver has been removed, towards the station with which he desires to communicate. The upper sight on the rod is then moved vertically until the centre of the mirror, the sight, and the distant station are truly aligned. Hence when the flash from the mirror is directed on to the sight it is in true line with the distant station, and can be seen by the observer there. This will, of course, be whenever the angle of the mirror is raised; when depressed, or in its normal position, the flash rests upon a cross-piece on the rod, and, according as the sun's horizontal and vertical motions cause the flash to deviate from the true line, the signaller is able to see and to correct the error by means of the adjustments on the instrument. The observer at the distant station, having seen the bright starlike appearances, sets his instrument to the point at which they appear and acknowledges the fact, and the parties being thus placed in communication, the interchange of messages proceeds upon the system we have mentioned, namely, the Morse alphabet.

By adopting the Morse system of dashes and dots (see Art. 1003, p. 764) Mr. Mance has been able, on a fine day, to make himself understood by an observer many miles off, as easily as one electric telegraph operator makes himself intelligible by another.

There are special arrangements for signalling with the sun behind the apparatus, by means of a reflector; for signalling at night, and for signalling either from fixed or variable positions. This sun-telegraph has been for some time employed in India with great success. The signals conveyed have been easily read in ordinary weather without telescopes for a distance of fifty miles, and, under favourable conditions, messages can be signalled and interpreted without telescopes for a distance of from eighty to one hundred miles. Signals by this instrument have been successfully exchanged by observers between the dome of St. Paul's and the Crystal Palace. For military purposes this mode of signalling would be invaluable. In time of war, telegraph wires are easily destroyed, while the heliograph might be so placed as to be out of reach of the enemy. From its inexpensiveness it might also be used in place of the ordinary telegraph wires, in countries where the erection of electric telegraph stations and wires would not be remunerative.

PART V.

ASTRONOMY.

1011. THE word "astronomy," composed of ἀστήρ, a star, and νόμος, law, is used to signify what can be learned respecting the objects visible in the sky, as to their distances, sizes, motions, and relations to this earth. When the earth is viewed in its totality, and regarded as it would be seen by a spectator at a great distance, it is found to be similar to some of the celestial bodies, so that it has to be considered along with them.

There are two distinct modes of regarding the celestial bodies :

First, we may study their distances, shapes, sizes, and motions, as appearing to an observer, without asking any questions as to causes, or seeking any explanation of the appearances. This is the department called Descriptive or Geometrical Astronomy, and includes all the knowledge attained on the subject up to the time of Newton.

Next, we may study the powers or forces that originate and sustain the various movements, and determine the shapes, sizes, and distances of the several bodies. This is to treat the celestial movements exactly as we should treat projectiles or other moving bodies in the earth.

It was through Newton's discovery of universal gravitation that the computations of terrestrial forces could be extended to the moon, the planets, and the other celestial masses! By such means, the various appearances are not merely described, but also explained upon mechanical principles. To this modern department is given the name Physical or Mechanical Astronomy. In the present treatise, only the leading principles of this part of the subject can be indicated.

ANALYSIS OF THE SECTIONS.

SECTION I.—*This* EARTH *is in form a globe or ball. Its diameter is nearly eight thousand miles. The globular form is the result of the mutual attraction or gravitation of its particles.*

At a distance from the Earth, nearly thirty times the Earth's diameter, is the body nearest to it—the MOON.

SECTION II.—*The Earth rotates or spins; thereby exposing its surface successively to the Sun, and bringing about the changes of day and night.*

SECTION III.—*The Earth revolves or travels round the Sun in the period of* 365¼ *days, which makes our year. From the direction maintained by its axis of rotation, while circling round the Sun, there are produced the changes of the Seasons.*

SECTION IV.—*The Moon is a smaller globe revolving round the Earth, as the Earth revolves around the Sun.*

SECTION V.—*The Earth is the third, as to distance from the Sun, and as to length of year, of a series of like globes called* PLANETS, *which are various in size, some larger, some smaller, than the Earth. There also revolve round the Sun other masses, very peculiar in their characters, called* COMETS.

SECTION VI.—*The* SUN *himself is the nearest to this Earth of innumerable self-luminous bodies, existing throughout illimitable space, which, owing to their distance, appear to our sight very small. These are the* STARS.

SECTION I.

"*This Earth is in form a globe or ball. Its diameter is nearly eight thousand miles.*"

1012. Canals for inland navigation are now common over the civilized world, and their bottom, in order that the depth of water in them shall be everywhere the same, must be made, not a straight surface represented by the line A B C (fig. 297), seen level at B, but as part of a hoop or curved surface, D B E, sinking downward from the straight or tangent level, A B C, taken at the point, B, very nearly eight inches for the first mile from B.

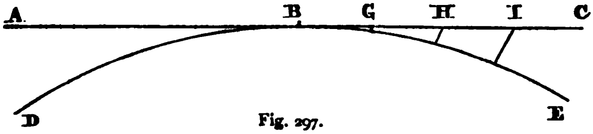

Fig. 297.

The important fact is to be remarked that the sinking from the tangent line, at double distance from B, is not *twice* eight inches, as might be expected, but *four* times eight; at triple distance, is not three times, but nine times as much, and so on for other distances, as the squares. Thus, the distances in miles being 1, 2, 3, 4, &c., the squares are 1, 4, 9, 16, &c.; and the inches of descent are 8, 32, 72, 128, &c. For greater distances the descent is calculated in the same way, and it is found that at a distance of 10 miles, it is 66 feet; at 14 miles, 150 feet; at 150 miles (the distance at which the Peak of Teneriffe comes into view over the watery horizon), the descent is 15,840 feet, or nearly three miles,—the height of that mountain.

It is to be observed that the rule explained here for heights and distances tells also what breadth of sea is visible from any given elevation above its surface, whether from the mast of a ship or from the land. The diagram exaggerates some of the proportions to render the effect more apparent.

A simple mode of proving the fact of this sinking down of the true level of a canal from the tangent or apparent level, and of ascertaining its amount is, to set up in the middle of a straight canal a row of poles, rising each, say, ten feet above the surface of the water. If the row be quite straight, a person looking along with the naked eye, or with a telescope, from near one end, can see only the nearest pole, for it would hide all the others, because light moves in straight lines. But if on these poles cross-pieces are affixed at equal heights, say of five feet above the water, and if the telescope, set level at that height, is then directed along the level, instead of the nearest cross-piece hiding all the others, as is true of the vertical poles in a straight line, it leaves them all visible in a curve, like pins projecting sidewise from the rim of a wheel, and the cross-piece on the pole standing at the distance of one mile from the station, B, would be found to appear just eight inches below the apparent straight level, as judged of by the telescope levelled at the station, B. The cross-pieces more distant than one mile, would be found to be lower by increasing differences, as seen in the figure at G H I, &c., and in the tabular statement given above.

1013. In whatever part of the earth this experiment is made, the like results are obtained, proving that the degree of convexity is, in round numbers, the same everywhere, and, therefore, that the earth is really a sphere. There is a slight deviation to be afterwards explained, due to the rotation of the earth. Now a simple arithmetical computation tells that a dip of eight inches in the first mile belongs to a globe of very nearly 8000 miles in diameter. The log-books of the ships that have sailed round it measure the circumference, and confirm the same estimate.

The most accurate mode of learning the earth's size is by measuring a degree of latitude in any arc of the meridian. This mode was actually adopted two hundred years before Christ by Eratosthenes, in Egypt, and was the first approach to an estimate of the size of the earth. Many careful measurements have been made in modern times, and from them we ascertain that the polar diameter of the earth is 7899·2 miles, and the equatorial diameter 7925·6 miles; the difference being 26·4 miles, and the mean diameter 7912·4 miles.

It is the same kind of experiment modified, and yet more simple, when in winter the poles are set up on the frozen surface of a canal or a lake. It is still the same when, instead of fixed poles in the water, the masts of two similar boats are used, on which telescopes are fixed. Let A and B (fig. 298) be two such boats on a straight canal. Telescopes, O, S, on their masts, set level while near, would point to each other; but as the boats separated, would have their axes or lines of sight pointing gradually higher and higher as the distance increases, according to the law above explained. At the distance, *a b*, the boats would have become what sailors call hull-down, or with the body of one vessel concealed from the view of persons on the deck of the other, and the telescopes could see, over the convexity of the globe between them, only the parts of the masts above that level.

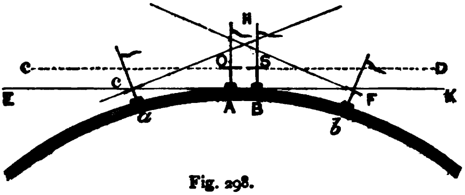

Fig. 298.

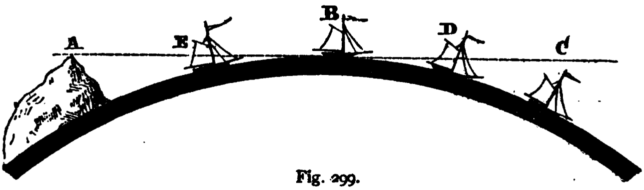

Fig. 299.

Fig. 299 represents the same ship, viewed from the same cliff on the sea-shore, A, at different distances. The dotted line, A B C, is the line of sight touching the surface of the convex sea when the ship is at B, commanding only part of the rigging at D, and seeing nothing of the ship at C.

1014. There is an interesting case, which in many situations on earth offers itself to notice, namely, where a spectator at E (fig. 300), in looking along the apparent level-line at A, just sees the top of a hill at B, and of a second loftier summit at C, and of a third loftier still at D, apparently all on the same level. The summit, D, might be one of the Andes, 25,000 feet high, and the others lower as less distant, according to the rule above explained; and in any such case the height being known, the distance is known, or the distance being known, the height is known, by computation.

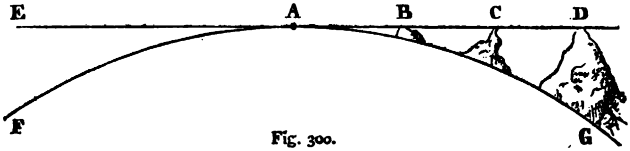

Fig. 300.

The surface of the convexity or bulge of the sea, existing between a spectator and a distant object, is called the water-line or natural horizon. It is always of course beneath the tangent, or apparent level, passing through the eye of the spectator; and the angle of depression is called the *dip of the horizon*, which is greater or less, according as the spectator is placed high or low above the level of the sea. For the use of mariners, books on navigation have a table, stating the amount of dip for different heights of the observer's eye.

1015. The following facts illustrate, and are explained by, what has now been said of the form of the earth.

When two persons approach each other from opposite sides of a river to pass over a bridge, of which the general surface is part of a circle rising high in the middle between them,—as was true of many bridges in former times—each sees first only the hat and head of the other, and then gradually the whole person. After passing they disappear from each other in the reverse way, the feet and lower parts of the body first, the upper part the last. So, on a much larger scale, two ships, approaching over the convex sea, exhibit to telescopes first their upper sails and rigging, and after they have passed each other, lose sight first of the lower parts. As they vanish they are first *hull-down*, then *half-mast-down*, and so on.

A ship departing directly out to sea soon appears to persons near the shore, hull-down, and to have got beyond a distant wall of water. A spectator on a height near the shore, as a lofty building, still sees the whole vessel.

Ships at sea, which are hull-down to persons on the deck are fully seen by the lookers-out near the mast head; and distant land may be seen from the mast-head over the bulge of the sea, where persons on deck see nothing.

The extensive plains in America called *prairies* and *pampas*, which are nearly as level as the surface of the sea, exhibit the same phenomena of hiding by their bulge distant objects from persons travelling over them.

Rivers crossing such level tracts are not, as generally supposed, straight gently-inclined planes, but portions of hoops, of which the parts towards the mouth of the river are a little nearer to the centre of the earth than the parts behind. It seems strange, until explained, that a ship may be seen hull-down though floating on a higher part of a great river.

When the sun appears half set over the sea, as at S in fig. 301, it is the substance of the convex water which hides the half, unseen by people on the low shore, for they have only to mount a little and they will see all again.

1016. A ship near the centre of a scattered fleet may see the distant ships all round, beyond the water horizon, half-concealed, as if to that extent submerged, at T. This appearance is more striking where the ships have a background of high mountain, M, beyond them. They then appear as if they were aground between the near water-horizon and the shore beyond

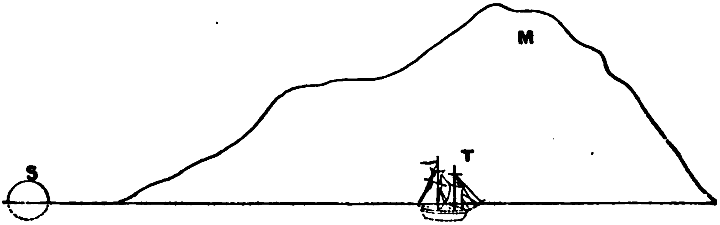

Fig. 301.

The sun sets entirely to people on a low plain, or on the sea-shore, long before the inhabitants of neighbouring hills have lost any of his beams. And the peaks of very elevated mountains are seen after sunset shining as brightly as the moon, so long as the sun's rays continue to reach them.

Near the border line, between the enlightened and the shaded portions of the moon in her quarters, the telescope sees always a number of irregular luminous spots, as bright as any part of the shining surface. These are the summits of mountains receiving the slanting rays of the sun, while lower parts near are still in the shade.

It has seemed strange that after sunset the song of a lark, invisible from the earth, should still be heard by people below. The explanation is, that the blithe bird on the wing may still have sight of the sun, when from eyes below he has quite vanished.

Aëronauts, who, in descending, reach the earth just after sunset, may see the sun again, and therefore can make an artificial sunrise, by throwing out some ballast and so remounting into the air.

If the inhabited earth had been, as believed of old, a broad plane surface, beyond the edge of which the sun and stars in setting had to descend, sunset and sunrise would have happened to all the world at the same moment. But, in fact, when the sun sets over the sea, to people on one part of a coast, the telegraph from a part farther west can report that to them he is still at a considerable elevation; and in all parts of the earth he sets and rises just as much later as the place is farther west.

" *The globular form of the Earth is the result of the mutual attraction or gravitation of its particles.*"

1017. The attraction of gravitation, considered as a property of all matter, was explained in the introductory chapter, Art. 13. Under any mode of attraction whatsoever, a mass of loose particles will assume the form of a globe or sphere. If water be allowed to escape through a small opening in the bottom of a glass tube, it appears as a mass rounded below, and increasing until its weight is greater than the attraction between it and the tube above. It then falls as a round drop, the mutual attraction of the particles being equal in all directions, producing this form. The successive drops are all of the same magnitude, and their number in a given time measures the quantity of liquid fallen.

Dew accumulating on the leaves and stalks of plants, takes a similar globular form. Small quantities of quicksilver scattered on a level table exhibit it also very remarkably by their reflecting light strongly, and if several of these are gently pushed together they at once coalesce and form a larger globule flattened a little on the under side, which rests on the table. Still more complete instances of this kind are the little perfect spheres of the lead-shot used by sportsmen. These begin as melted lead showered down from a height, and the drops are solidified by cooling during their descent. In small masses of liquid, the attraction of particles is, from their proximity, very strong, and is called cohesive attraction. (See page 10.)

1018. But the general attraction, named by its discoverer, Newton, gravitation, acts at all distances. Thus, a plummet, or ball of lead, hanging by a thread, when it is over an extended plain has the thread pointing directly downwards, or at right angles to the surface of still water; but if the experiment be made near a steep mountain, the ball and string lean, or are attracted towards it, and by delicate tests are found to be less attracted towards the mountain than towards the earth below it, owing to what is called its weight—only because the mountain is so much smaller than the earth, notwithstanding that its influence is increased by its centre being nearer.

A strictly corresponding result is obtained by the experiment of balancing two little balls of metal, A and B (fig. 302), at the end of a horizontal rod of wood, hanging from a lofty support, C, by a single wire, C D. If, when the loaded wood is perfectly at rest, a heavy mass of any kind is brought near to the side of one of the balls, it attracts the ball, twisting the suspending wire in a degree which indicates the force operating. This arrangement constitutes a *torsion balance*.

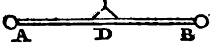

Fig. 302.

It is gravitation that makes the whole earth take the form of a globe. Although now firm and rigid, at least in the surface crust for many miles down, the mass of the earth was formerly liquid or soft, and in that state there was nothing to hinder the free movement of the particles under their mutual gravitation. As all liquids are seen to find their level, this means that all portions of the surface tend to become equally distant from the centre. If any portion were elevated above the rest—that is, were farther removed from the centre—it would flow down, or centreward, until an equal distance was attained. This is the true meaning of being "level" on the surface of a globe.

That the earth's surface is not perfectly level, but is made up of heights and valleys, sometimes very steep or abrupt, is owing to internal forces which have upheaved parts of the superficial crust after it had become hardened or coherent. This coherence resists the force of gravity, which operates only on the particles loosened by the action of air and water.

Although the globular form of the earth is compatible with mountains of a considerable elevation, as the Himalayas, whose highest summits exceed five miles above the sea level, these heights are insignificant compared with the entire diameter, being only about one sixteen hundredth part of the whole. In a globe of four feet diameter, the tops of the highest Himalayas would have to be represented as projections about the one hundred and sixtieth of an inch.

The globular form is the reason of the inequality of the sun's heat on different parts of the earth, as explained in the section on HEAT.

"*At a distance from the Earth, nearly thirty times the Earth's diameter, is the body nearest to it, the Moon.*"

1019. That the moon is nearer to us than any of the other celestial bodies is proved by the fact that when she comes over the place where the sun, a planet, or a star is at the time, she hides them from our view. When this happens with the sun it makes a solar eclipse; when with a star, or a planet, it is called an occulting, or occultation.

The means of ascertaining the distances of the heavenly bodies from the earth may be understood by the following considerations:—

In the section on LIGHT it was explained that in regard to objects comparatively near, persons judge of the distance by several means, but especially by the degree of convergence, or angular approach, of the axes of the two eyes, which have to meet at the object in order to see it distinctly. This is recalled in the adjoining diagram (fig. 303), where the small circles mark the eyeballs, from which lines going to A B C D show different inclinations or convergence of the axes. The angle or corner formed at the meeting of the axes at A is evidently greater than that at B, and still greater than that at C, &c. The person is conscious of the difference of effort required, at the different distances, to cause the axes to converge sufficiently, and that consciousness serves as a measure.

1020. Now to judge accurately by that angle of convergence, in regard to objects very distant, like the moon, sun, or a planet, we employ, instead of the two eyes, two telescopes, placed at distant stations, or one telescope used successively in two stations, and then measure accurately the angles of direction of the telescopes, whose axes meet at the object.

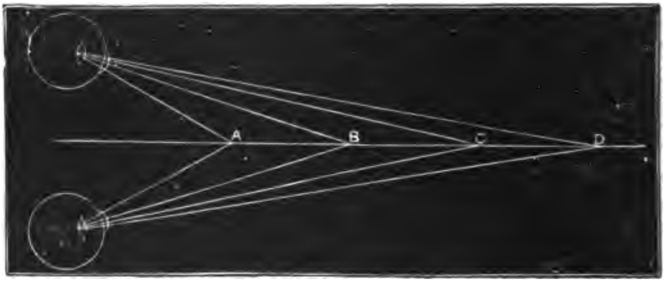

Fig. 303.

The fixed relation of such angles and distances may be rendered intelligible by a simple illustration. Let the lines, A G and B I (fig. 304), represent parts of the parallel sides of a long straight street, with a row of lamp-posts in it, A D E F G, about the width of the street apart. Let a pocket-watch then, with large dial face, be placed on a table at B, directly opposite to the lamp-post, A, where the crossing line, A B, forms a square corner or right angle with the line, A G, lying along the street. Let the minute-hand of the watch point to twelve

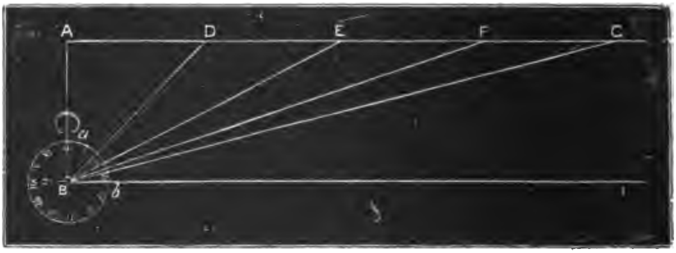

Fig. 304.

o'clock, and at the same time to an attendant standing at the lamp-post, A. If the attendant then move to the post, D, and the minute-hand be turned to follow him, the eye of an observer through a small telescope, placed in the direction of the hand of the watch, will see the attendant in the direction, B D, which may be represented by a thread stretched from B to D. That thread will cross or cut the divided circumference, *a b*, of the watch, then serving as an angle-measure instead of a time-measure, at a certain angle (here of 45°). The attendant, continuing to advance, would reach the posts, E F G, &c., in succession, and would be seen along the lines, B E, B F, B G, &c., cutting the curve, *a b*, at different points nearer and nearer to *b*, and forming angles of less and less magnitude, with the line, B I. This process might be continued until the eye could no longer distinguish the more distant lamp-posts, nor estimate aright the lessening portions cut off on the divided curve, *a b*. But so long as these could be distinguished, every distance among the posts would form its own distinct angle, and he who could read the angle would always know the corresponding distance of the lamps on the prolonged line, A G. By such an experimental process, and still more accurately by computation, a table of tangents is constructed, showing the distances and angles that mutually correspond.

A common watch is here referred to as an angle-measure, because it is so familiar, and because the hand, in moving forward, so evidently divides the space around the axle into all possible angles. The instruments actually used for measuring angles have always a metallic circle, or portion of a circle, accurately divided into equal degrees, or parts of a degree, over which an index travels. So perfect now is the manufacture of such instruments that they enable the eye, when aided by a microscope, to distinguish less than the hundred-thousandth part of the circumference of a circle.

1021. It is a very important fact that, under certain circumstances, by measuring the angle formed where two straight lines meet, the length of one of them pointing to a distant visible object can be accurately known. This depends on the remarkable properties of the *triangle*. It is roughly exhibited when a string, A B C (fig. 305), is employed to support a picture-frame, D, on a wall, the string passing through two rings, B and C, on the frame, and resting on a nail at A on the wall; or, when a piece of thread of any length, having its ends joined to form a loop, is laid on a flat table and is opened out into the form of a triangle by outward pressure made at any three points.

The properties referred to are, first, that whatever the shapes of triangles be, as here, of A, E, F, G, H, the sum of the three angles of any one is always exactly equal to two square corners, or right angles, so that when any two of the angles are known, the third also is known ; and second, that, of the six particulars named of sides and angles, if any three, one of these being a side, are known, all the six are knowable, either by simple computation or by drawing the figure of a convenient size on some flat surface.

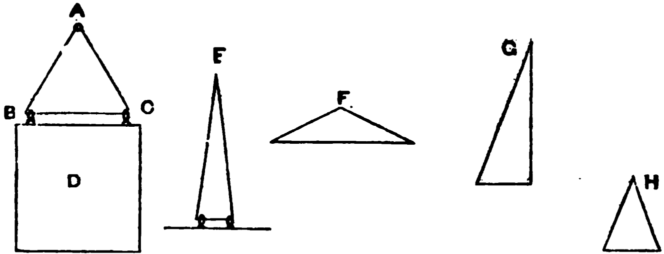

Fig. 305.

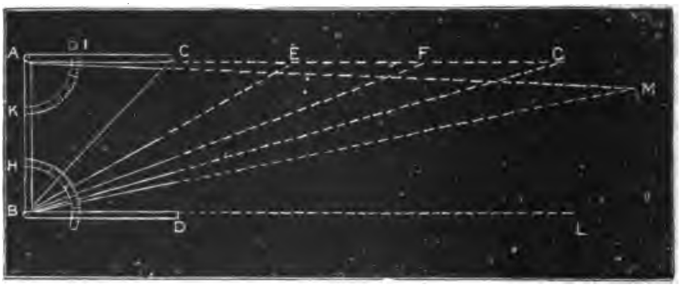

Fig. 306.

The simple arrangement here sketched further illustrates this subject. A B (fig. 306) is a flat ruler or rod, in wood or metal, about a yard long. A C and B D are similar rods of any length, hinged movably to the ends, A and B. The rod, A B, called the base of the figure, has, affixed at H and K, two arcs, or portions of circles, H I and K I, divided into degrees, by which the angles formed at A and B by the movable arms and the base can be measured. Laying this on a table, and causing the movable arms to point to any object, the visual rays, indicated here by dotted lines, will meet at the object, as M, to form an angle which, by the tables spoken of, or by computation, tells the distance of the object. By such a rude instrument, a person without moving from his chair can judge of the distance of any object within view, in a room, a garden, or field.

The angle to be determined in all such cases is called the angle *of parallax*, the reason of which appellation is thus to be explained. The figure, A B C D (fig. 307), shown here is called a parallelogram, because its opposite sides are parallel to each other; that is, are at the same distance apart wherever a directly transverse or cross-measure is taken, and therefore, however far prolonged in either way, they would never meet. But a line called a diagonal, drawn between opposite corners of the parallelogram, as from B to C, or from A to D, is not *parallel* to the sides, but has a *changed bearing* called *parallax*, and the sharp angle formed at the corners of the parallelogram between the diagonal and the side is the angle of parallax.

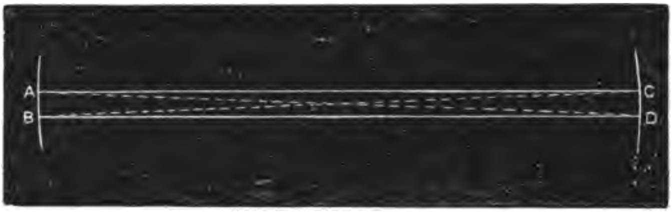

Fig. 307.

If an observer at A look through a telescope with graduated arc towards an object at C, bearing directly east from him (or in any other exactly ascertained direction), and if he then shift his station to a certain known distance, B, at right angles to the line, A C, and he again look towards the object, C, he finds its bearing changed from being directly east to the other line, B C, inclining north of east by the sharp angle, D B C, at the corner, B. This is called the angle of parallax. Whatever part of a whole circle that angle is, just such part of the circumference of a circle which has C for its centre, and the distance, C A, for its radius or semidiameter, is the distance, A B, which has been measured; and from that part being known the whole circumference is known, and, consequently, the semidiameter of the circle, which was the distance sought.

In regard to the distance of the moon from the earth, the shape and size of the earth being now well known, the distance of any two remarkable places upon it is also known, and the straight line of distance between any two such places may serve as the base line for measurement. The places that have been chosen for the purpose are the two observatories of Greenwich and the Cape of Good Hope, at which angles can be measured which will declare the angle at the summit of the figure, M (fig. 308), where the moon is supposed to be. A still simpler mode of ascertaining the angle of this parallax is to measure the apparent angular distances, as seen at the same moment from these places, between the moon and a known fixed star. The distance of the moon from this earth is by these means ascertained to be 240,000 miles nearly, or thirty times the diameter of the earth. Knowing the distance in such a case, and the apparent diameter, because the moon, like all the other heavenly bodies, is globular, the size of the moon can be computed. The diameter is thus estimated to be 2160 miles, rather more than a fourth part of the diameter of the earth; the bulk of the moon is consequently nearly a fiftieth part of that of the earth.

Another method of confirming the same result, although in itself not so exact, is the following:—

1022. Let the circle, G (fig. 308), represent the earth; M, the moon over the head of a person at E; and M H, part of the apparent path of the moon travelling round the earth, always at nearly the same distance from the centre of the earth, G. It is evident that the moon, when at M, is nearer to a spectator on the earth at E by half the diameter of the earth —4000 miles—than when she is setting beyond the horizon at H. According to the law of Optics—that an object appears smaller in proportion as it is farther away, the moon when at H should appear smaller to the spectator at E than when at M. Now, when measured by a fit instrument, it does appear smaller by just one-sixtieth part of its diameter. This proves, therefore, that 4000 miles is the sixtieth part of the moon's distance from the earth; now, sixty times 4000 is 240,000.

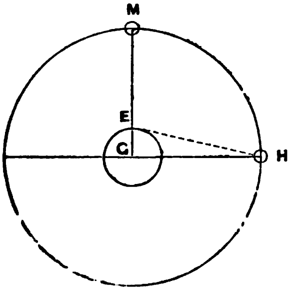

Fig. 308.

This experiment proves another striking fact, namely, that in the six hours between the moon's being over a person's head and its setting, its distance is increased by nearly 4000 miles.

By kindred means to those above described, astronomers have ascertained the distance of the sun. It is four hundred times greater than that of the moon, being ninety-one and a half millions of miles. The distances and magnitudes of the other heavenly bodies are so vast, that the human mind has difficulty to conceive them; and the angle of parallax which measures them becomes so small that instruments of extreme delicacy, and the aid of strong microscopes to read the indications, are required for the purpose.

SECTION II.

"*The Earth rotates, or spins; thereby exposing the surface successively to the Sun, and bringing about the changes of day and night.*"

1023. Judging from first appearances, people necessarily supposed that the earth stood still, while the stars moved round it. This inference would be confirmed by a natural prejudice founded on the supposition that the motion of the earth would endanger the stability of everything on its surface. A more exact attention to the phenomena of moving bodies dispels this prejudice. Motion, if perfectly equable, disturbs nothing, and is unfelt by the living beings that partake of it. Many illustrations of this fact can be given.

Aëronauts in the car of their balloon, when moving a hundred miles an hour, have no sensation of being in motion, and if surrounded by a cloud which prevents them from seeing objects around them, they cannot know in what direction they are moving. The same is true of persons on board ships drifting along in sea-currents out of sight of land, as frequent disasters have proved. A person sitting in the cabin of a ship at anchor, if occupied in reading or writing while the ship is swinging round with the turn of tide, has no perception of the change. A man seated in a chair suspended by a rope from a high ceiling, if his eyes are covered, has no sense of any turning motion softly given to his seat. A person in a small floating boat or tub, surrounded by a floating screen which hides from him all beyond it, cannot know, when any gentle motion is produced, whether it is in his boat, or in the screen, or partly in both.

Uniform motion of this globe, then, however rapid, would not be perceived by the inhabitants. The motions of walking, riding, being driven in a carriage over a rough road, being tossed in a boat on a rough sea, and so forth, are contrasting examples. (See Art. 156.)

At the time when the stars were regarded as insignificant in size, and not very remote in distance, people might suppose it not unlikely that the entire concave of the heavens should revolve round the earth. But, with our present knowledge of their vast distances and magnitudes, such an enormous sweep as they would have to make every twenty-four hours becomes in the highest degree improbable; while many circumstances suggest that the changes of day and night, and other phenomena, formerly attributed to the motion of the heavens, are due to the motion of the earth itself. We shall first survey the appearances themselves.

1024. Let a person, just after the setting of the sun, of which the intense brilliancy during the day prevents all smaller lights from being seen, ascend to the house-top or other eminence which commands an unobstructed view of the horizon around, and let him there contemplate at leisure the nocturnal sky. He may in the morning have seen the sun appear to rise in the east, and gradually move across the sky to set or disappear in the west. As the setting sun's light fades, he finds himself apparently in the centre of a stupendous vault or concave half-globe, thickly studded with luminous objects, which he has been taught to call stars. Among these he perceives as little order of arrangement as among the first drops of rain falling on a white pavement, but soon, individual stars are distinguished by their greater brilliancy, and others by belonging to certain groups, which bear some resemblance to familiar forms on earth, as of square, cross, triangle, and so forth. He soon perceives that all the stars have a movement towards the west, like that of the sun during the day, and that those near the western horizon are setting or disappearing, to follow the sun, while others are rising into view in the east, and maintaining undiminished, the splendour of the spectacle. In the course of the night, if the observer watch to the end, he will see, not only that starry half-globe or concave which was overhead when the sun disappeared, but also the whole of another half, which, as the night advances, gradually takes the place of the first. With the sun's light returning and producing the dawn of next day, the feebler lights of the stars are first dim, and soon cease to be at all perceived by the naked eye; but a good telescope can see and follow them moving on all through the day, just as the naked eye did during the night; and those subsequently rising in the east are found to be those which twelve hours before set after the sun in the west. The observer thus finds that he has seen the whole of the surrounding firmament in which the world exists, revolving like the continuous interior of a great wheel. The stars which rise and set nearly with the sun are, for the time, less conspicuous than the others, owing to his overpowering light; but when the sun gradually changes his place among them during his annual circuit, all are, in like manner, alternately dim and bright.

Now for thousands of years men have been watching the appearances of the stars, and from observing that their relative positions have remained sensibly unchanged, have called them the *fixed stars*, to distinguish the general mass from a small number, which seem to move about among the others as the sun does, and are called *planets* (from the Greek word πλανάω, to wander).

1025. The spectacle of the nocturnal sky above described is rendered much more interesting by having at hand a globe, formed of wire, like a bird-cage, as here represented, with a spindle, S N, through its centre, C, on which it turns. One end of the spindle, N, is to be directed to the north pole of the sky, and the other end, S, to the south. At places on or near the equator, as in our colony of Singapore, in the Strait of Malacca, the spindle appears to the inhabitants to be horizontal, as here shown from N to S. A person sitting near the table which supports this globe, so as to be able to look through a small ring at its centre, C, towards every star above the horizon, may attach in some convenient way, on the surface of the globe at the point which is in visual contact with the star, a small glass bead to represent it. He may then maintain such bead in contact with the star, by gradually turning the globe round as the star seems to travel westward towards the setting; and in the meantime he may employ himself in affixing other beads to represent the other most conspicuous stars then seen. These representatives of the stars will set with them, by sinking under the level of the spindle, S N, which in-

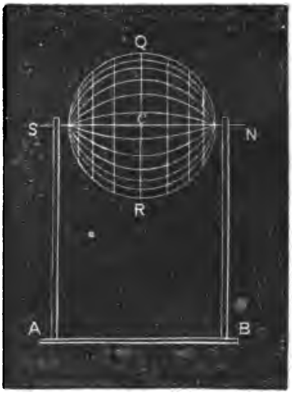

Fig. 309.

dicates the level of the horizon. During one night, thus, a person watching until dawn of the new day, may complete an interesting model of the whole sky around this earth, as existing both above and below the horizon, showing its most conspicuous stars in their true relative positions. In succeeding nights he may render the model more complete by adding other stars of inferior magnitude. Such a globe may be connected with a common clock, so as to turn round its axis once in twenty-four hours, and it will then exhibit uninterruptedly the changing places of all the stars marked upon it, whether they are above the horizon or below, and it will point through the day to the parts of the sky where the stars, although unseen then by the naked eye, are to be seen by means of a telescope properly directed.

1026. While the figure (fig. 309), half covered by a card up to the axis, exhibits the apparent motions of the sun, moon, and stars, all vertical, as seen by persons near the equator, the adjoining figure half-covered indicates the apparent motions, all level, which are seen near the poles. The axle of the globe, when similarly half-coloured and placed obliquely, pictures the appearance at latitudes intermediate between the equator and poles.

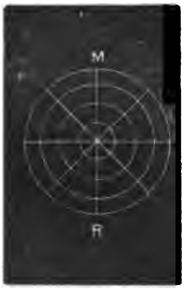

Fig. 310.

Such a globe of wire with beads is a rough model of the so-called Celestial Globe, now part of the common furniture of our libraries. It has the advantage, by being transparent, of being able to show both sides of the globe at the same time, and to allow useful comparisons to be made.

The globe of wire, made like a bird cage, leads the spectator to appreciate at once the importance of being able to give a clear name or designation to every part of the surface of a globe, distinguishing it from every other part. When on a chess-board a square is said to be in some certain row from the top, and some certain row from either side, it cannot be mistaken for any other square. So on a globe; if a spindle pass through its centre, circles of wire may be fixed round it, at equal distances from the ends of the spindle (called poles, from the Greek, πολέω, to turn), and they may be called circles of breadth or *latitude;* then other circles or lines of wire may be placed across these, cutting the equator at equal distances from one another, and reaching from pole to pole. These may be called circles of length or *longitude.* If all these circles have on them divisions into equal parts, all numbered, every spot or point on the surface of the globe will have its own latitude and longitude, perfectly distinguishing it from every other.

1027. A globe formed of white marble or other such material, if at rest, has no mark upon it to distinguish one part from another; but, if it be caused to rotate or whirl, every part instantly acquires certain peculiarities of motion, which clearly distinguish it. If a globe suspended by a twisted cord have small spots of any kind on its surface, as of ink spattered upon it, the spot to which the cord happens to be attached will appear to be at rest, as a pole of rotation, and every other spot will be describing a circle of latitude round the pole, which circle will be larger as it is further from the pole, until the equator, or the middle circle equally distant from both poles, is reached. A pen or pencil held to touch the turning globe at any spot would mark a circle of latitude there. If lines were then drawn directly from pole to pole across the equator at equal lateral distances, they would form lines of longitude.

It is readily perceived that the appearances of motion presented to the common eye among the heavenly bodies around the earth would be exactly the same, whether the bodies revolved round the earth as a centre, or the earth rotated as a central mass within a firmament at rest. It follows, therefore, that there are everywhere points or situations exactly corresponding in the starry concave above, and on the globular earth below. There must be in each hemisphere apparently fixed points, to be called poles, round which every other point will seem to revolve, and there must be perfect correspondence between what are called the latitudes and longitudes below and positions in the sky above. It is thus that a mariner bound to a small island like St. Helena, situated in the middle of a broad ocean, and which he cannot see until he arrives close to it, keeps his eye on the part of the sky which he knows to have the latitude of the island, and sails until he brings that part nearly over his head.

Among the general considerations bearing on the question of the earth's constant rotation on its axis may be mentioned the fact that all the other planetary bodies visible in the sky to our telescopes have such a rotatory motion, and even the sun himself is seen so to turn once in twenty-five days. Spots, which are frequently visible on his surface, prove this.

1028. A strikingly ingenious and beautiful experiment in proof was devised by M. Foucault, of the French Academy, as follows. If a pendulum is caused to swing, it performs its motion in one direction or plane, as from north to south, and will not deviate from that plane unless urged by some new force, even if its suspending thread is twisted. Accordingly, a pendulum hung from a support over the pole of a library globe set with its spindle vertical, will not be influenced by the turning of the globe beneath it, and will therefore show how far and how fast the globe may be made to turn under it. Similarly, a long pendulum caused to vibrate from a fixed support, over the centre of a large clock-dial laid on the ground near a pole of this earth, continues to move in the same plane, while the earth turns, and the line of the pendulum's motion continuing the same while the earth turns, indicates the fact, and the rate of the earth's rotation. If the experiment were made exactly at the pole, the apparent motion would be as rapid as that of the hand of a sidereal clock. At different distances from the pole it is proportionally less rapid.

A ball of metal suspended like a plummet from a point in a lofty ceiling will hang over a point in the floor which is directly beneath the point of suspension ; but, if the ball be allowed to fall freely from the point of suspension, it will reach the floor considerably to the eastward of a mark on the pavement beneath the plummet. The reason is that the surface of the earth is rotating eastward, and as, in a turning wheel, parts distant from the centre have swifter motion than parts near to it, a body let fall from aloft, preserving its original onward velocity, will reach the floor in advance of where it would hang as a plummet.

1029. Many of the most remarkable motions observed on the surface of the earth, as the winds in the atmosphere and certain great currents in the seas, have their force and direction much influenced by the whirling of the earth. Explanations are given from pages 286 to 288.

The phenomena of the trade-winds, hurricanes, cyclones, &c., and of such movements in the ocean as the warm Gulf Stream, which sets across the Atlantic from the Mexican Gulf to the western shores of Europe, were little understood until within the last fifty years ; and the value of the new knowledge may be judged of by the vast improvements in navigation made within that time.

Inspection of the globe sketched in Art. 1025, or of the common celestial globe placed in libraries, explains readily the following terms :—*poles* of the globe,—the *equator*,—*latitudes* and *longitudes*,—the *zenith*, or summit of the sky, over the head of an observer,—the *nadir*, a corresponding point directly below,—the *azimuth* of a visible object, or the relation of its bearing to the *cardinal points* of the compass, *north*, *south*, *&c.*,—the *horizon*, or bounding level line on which the concave sky seems to rest.

The business of the astronomer is chiefly to study and measure the position and motions among the heavenly bodies, in relation to the poles, horizon, &c., as viewed from this earth, which is itself constantly in motion. By the apparent places of the heavenly bodies so observed, he learns the true places and motions, and can foretell what is to happen in future time.

A perfectly constructed globe of metallic circles, all accurately graduated or divided into the usual degrees, minutes, and seconds, with a good telescope at its centre, turning in any direction,—the whole being firmly supported on a suitable frame,—would enable an observer to make most of the measures which the astronomer desires to make, and might be called a small portable observatory. So delicate, however, and requiring such extreme precision, are many of the observations to be made, that it has been found necessary, instead of many small elements joined together, to have large instruments placed apart. A fit building erected in a suitable locality, furnished with such instruments, is called an *Astronomical Observatory.*

1030. The chief instruments in an observatory are, the large telescopes with graduated circles and the time-keepers. A good telescope can gather a thousand times more light from a distant object to form its image on the retina, than can enter the pupil of a naked eye. In the observatory are to be seen: 1st, the *transit instrument*, of which an outline is here given—a powerful telescope, A B, turning on a level axle, firmly supported at E and F, lying directly east and west, which causes the telescope to sweep along the meridian line from the south point to the zenith and beyond. Through this is watched the instant of a heavenly body's passing the meridian line. The field of view of the telescope is crossed by several vertical lines, and the instant being

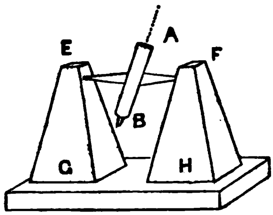

Fig. 311.

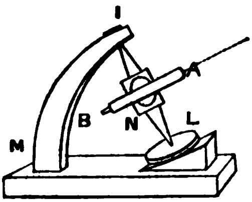

Fig. 312.

noted when the star passes each of these, the average of all gives the exact time. 2nd, the *equatorial telescope*, sketched in fig. 312. The telescope, A B, is supported on an axis which is made parallel to that of the earth, so that, as the earth turns, the telescope, having been pointed to any star or other object, follows that along its circuit. 3rd, the *mural telescope*, with large graduated circle. It has its axle fixed in the firm wall. It ascertains altitudes and polar distances very accurately.* 4th. the *observatory clocks*, showing both sidereal and solar time.

One matter of importance has as yet to be mentioned, which has to be allowed for by astronomers in their observations, namely, that the rays of light, which in empty space move straightly, do not so move when passing through the transparent medium of atmospheric air. They are then more or less bent or refracted according to the accidental temperature, moisture, density, &c., of the air at the time. A correction has to be made for refraction, as explained in the section on LIGHT, Art. 808, p. 578. In many astronomical observations, such as those made to determine the distance of the sun, a single second of an angular degree is an important quantity.

Mechanical View of the Earth's Rotation.

1031. The consideration of the original commencement of the earth's rotation belongs to the hypothetical speculations relating to the prior condition of the solar system. Once commenced, it goes on without abatement, so long as there is nothing to resist it. Although causes are supposed to be at work, tending to wear it away, as for example, the friction of the tides, yet there is no evidence of any sensible reduction in its rate within historical times. The effect of any loss of velocity would be to lengthen our day.

An important mechanical consequence of the rotation is the changing of the figure from an exact ball or perfect sphere to a flattened ball. If we measure the actual dimensions of the earth, which can be done by the means described (Art. 1013) for ascertaining the size of the earth, we find that it has a shorter and a longer diameter, the difference of the two being 26·4 miles. The shorter diameter is the *axis*, or the imaginary line round which it spins, the line that is at rest while all other parts are in motion. The longer diameter is called the *equatorial* diameter; it is at right angles to the other; that is, it crosses the axis at its centre. The fact is otherwise expressed by saying that the earth is flattened at the poles (extremities of the axis) and bulged at the equator.

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* In modern observations the use of the mural circle is abandoned, and a graduated circle is attached to the transit instrument, so that this instrument becomes capable of observing both time and altitude; it is then called a *transit circle.*

Now this is exactly what would happen as an effect of rotation, according to the doctrine of Centrifugal Force, as explained in Art. 161. When a body is put in motion, its tendency is to keep up that motion in the direction first given to it, and it resists change of direction, in proportion to its speed. This is otherwise stated by saying the force of a projectile is *tangential;* the body projected goes off straight, and cannot be constrained into a curved shape without some second force drawing it towards a centre, and it offers a certain amount of resistance to this central force. The projectile or tangential force may be so great as to overpower altogether the central force, so that the body flies off—not exactly at a tangent, for the central force still deflects it slightly, when it cannot retain it—but in a curved route, leading it farther and farther from the deflecting body.

Computing the magnitude of the earth, and considering that it performs a revolution in a day, we find that a point at the equator is carried at the rate of a thousand miles an hour, or about seventeen miles a minute, or nearly a quarter of a mile per second. This tendency counteracts in a small degree the force of gravity, so that a body weighs less at the equator, and a pendulum vibrates more slowly, than at the poles. Being thus less drawn to the centre, the body recedes to a greater distance than the matter at the poles; hence the slight bulging at the equator which the measurement discloses.

Calculation shews that if the earth were to rotate seventeen times faster than it does, that is, if it were to go round in little more than an hour and a quarter, the centrifugal tendency would balance gravity at the equator, and bodies there would have no weight at all: in other words, they would cease to be detained at the surface, and begin to fly off. The whole earth would then be a flattened cake instead of a sphere.

SECTION III.

The Earth revolves or travels round the sun in the period of 365¼ days, which makes our year.

1032. The reader, when acquainted with the two great facts already explained, namely, the spherical form of the earth, and its diurnal rotation, which causes the alternation of day and night, is prepared to understand the additional motion of its annual revolution round the sun, which causes the phenomena of the year with its seasons.

If a lamp stands on a table in the middle of a room, say at the height of five feet, and if a person walks round the table, the lamp will have an apparent visual contact in succession with the different objects on the wall at the same level. Or, if the person become stationary in the middle of the room, and the lamp be carried round, the same result follows. It would be a case still more closely resembling the facts of astronomy, if a great lamp stood in the middle of a racecourse in a dark night, when nothing could be seen but the house lights in the country around. A spectator carried round the course would see the central lamp coming into contact with the other lights in turn. The great lamp, in such a case, would represent the sun, and the smaller lights the more distant stars. Until mankind obtained the irresistible proofs that the earth on which they live is itself in rapid motion, they naturally concluded that all the apparent motions were in the distant objects.

It was evident that either the sun must be revolving round the earth, or the earth must be revolving round the sun; yet each supposition seemed irreconcilable with other parts of man's knowledge. For instance, if the earth was supposed to be fixed in space, the ancients could not imagine by what means it was so fixed, and they had to believe that the stars that they called fixed were retained in their relative positions by connection with a vast transparent or crystalline concave, which had a constant revolving motion.

1033. The proofs that the earth moves round the sun, and not the sun round the earth, are these:—

1. The sun is a much larger body than the earth; whence the likelihood is that the smaller body moves round the larger; just as it was considered more likely that the earth should spin about its axis, than that the whole starry sphere should perform a daily circuit round the earth.

2. It can be seen that all the other planets move in circles round

the sun. When their motions are tracked, we find they correspond exactly to revolutions about the sun, at different distances, and in different periods.

3. Some of the planets are seen occasionally to move backwards for a certain space, and then resume their regular or forward course. This is called their *retrograde* motion. If they were moving round the earth as a centre, this motion could not take place. It is consistent only with the supposition that they move, along with the earth, round the sun, as the common centre. The backward motion is only apparent, and it is due to the earth's motion, which alters our position as spectators.

4. All these facts are compatible with the supposition, which was actually entertained before the time of Copernicus, that while all the rest of the planets move round the sun, the sun himself, carrying the planets with him, moves round the earth, in a year, at a distance of about ninety-one millions of miles. However improbable this might be, there is no self-contradiction in it, at least until we take into account the mechanical explanation of the planetary motions, according to the law of gravity. But there is one circumstance that is incompatible with the sun's motion, and constitutes what Bacon called an *experimentum crucis* in favour of the motion of the earth. This is the discovery made by Bradley, called the Aberration of Light.

The most familiar example of this phenomenon is presented in a shower of rain, with the drops falling perpendicular. When a person stands still, the drops are felt as falling vertical upon his head, but if he move forward, they come slanting upon his face, and the faster he moves the greater the slant. Now light is proceeding in a shower from the heavenly bodies to the earth. If the earth were standing still, the rays would strike it directly, and the places of the celestial bodies would seem to the observer to be exactly what they are. But if the earth is moving, a slant is given to the rays, and the eye, judging from their direction as they reach it, assigns wrong positions to the bodies themselves. The amount of misplacement depends upon the relative velocities of light and of the earth in its orbit; and if the velocity of light were not so enormously superior to the earth's motion (ten thousand to one), the error might be very great. It actually amounts to twenty seconds of a degree, and renders it necessary to apply a correction to the observed places of the stars. Every star appears to describe annually a small circle, whose angular diameter, as seen without any foreshortening, is about forty seconds.

THE LAWS OF KEPLER.

1034. Before the time of Newton the facts regarding the revolution of the earth and the planets generally around the sun, were summed up in the three principles called the *Laws of Kepler;* they being discovered by him from a study of the observed movements of the different planets.

The first law is called the law of *equal areas.* If a line be supposed drawn from the sun to a planet, as the planet moves, that line describes or sweeps over equal areas in equal times. If a planet were to move in a circle, this would be a way of saying that its motion is uniform, or the same all round. If the planet does not move in a circle, but in an oval, then it is sometimes nearer and sometimes farther from the sun; and the law states that as it recedes or moves farther away its motion is slower; as it comes nearer its motion is quicker. The law of equal areas shows exactly how much slower or quicker the motion is according to the distance. It is otherwise expressed in a manner more easily adapted for calculation:—*The angular velocity of a planet's movement is inversely as the square of its distance from the sun.* If a planet were to pass from the distance of nine millions of miles to the distance of ten millions, its angular speed would be slower in the proportion of 100 to 81.

Let the figure represent a planet's ellipse, and let S be the place of the sun in one of the foci of the ellipse. If the planet start from A, the nearest position to the sun (*perihelion*), and move to C in a given time, the line joining the sun and the planet, called the *radius vector*, sweeps over the area, A S C. Suppose next that the planet is at B, the point farthest from the sun (*aphelion*), and that it moves to D in the time that it took to move from A to C; then the area, B S D, is equal to the area, A S C.

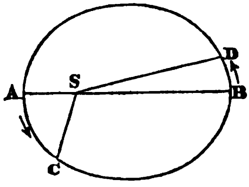

Fig. 313.

The second law of Kepler is the law of the *elliptic motion* of the planets. *The path of the plonets round the sun is an ellipse, the sun being in one focus.* This was a very great advance upon the earlier view of planetary motion, which represented the planets as moving in circles; a view that was difficult to reconcile with the unequal velocities at different parts of the orbits. But Kepler, by combining this law with the foregoing, rendered an exact account of the inequalities.

These two laws refer to the motions of any single planet. The third law is an interesting relation between the revolutions of the different planets. It was to be expected that the remoter planets would take longer time to accomplish an entire revolution about the sun ; and Kepler discovered the exact proportion between the two things—*mean distance* and *periodic times. The squares of the periodic times of two planets are as the cubes of their mean distances from the sun.* The periodic times, or periods of revolution, of the Earth and Mars are respectively 365¼ days and 687 days. Their mean distances are 91⅓ and 139⅛ millions of miles respectively. By squaring the first proportion and raising the other to the cube, the equality of the two proportions is made evident.

The same laws apply to the revolution of the moon round the earth (which can exemplify only the first and second), and to the revolution of the satellites of Jupiter around the planet. They also apply to the revolution of the strange bodies called comets.

Mechanical View of the Earth's Revolution about the Sun.

1035. The laws of Kepler above described involved no theory as to the forces or powers that keep up the vast movements of the planets, satellites, and comets. They gave the facts, however, with considerable (although not perfect) accuracy ; and by them the position of a planet at any time could be predicted. They prepared the way for the next step in astronomical discovery, which was made by Newton, and provided the mechanical explanation of the celestial motions, upon the very same principles as those that we apply to explain the flight of a cannon ball, or a stone thrown in the air. This was the beginning of mechanical or physical astronomy, and was necessary in order to accommodate the laws of Kepler to the facts.

The discovery of universal gravitation was the stepping-stone of this grand transition. The motions of the planets seemed to resolve themselves into two distinct tendencies—one towards the sun, the central tendency or attraction ; the other at a tangent to their course, by which they seemed ready to fly off into space, but for the check of the former or central tendency. There were thus two questions. One was, What is this central tendency, or solar attraction? Can we liken it or assimilate it to any other known agency or power? Newton surmised, and succeeded in proving, that the solar attraction is the very same power, on a great scale, as we see on the earth, in the fall of unsupported bodies, the power called gravity or weight. As a stone falls, or is pulled to the earth, so the moon is also pulled to the earth, only less strongly, on account of the greater distance; and so the earth and the other planets are pulled to the sun. If this were the only force ever impressed upon the planets, they would all have fallen into the sun long ago. But they are under a second force or tendency, called their tangential or centrifugal force, exemplified on the earth when a ball is shot from a cannon, which ball describes a curve before returning to the ground. The ball is under two forces; one is gravity, from which it is never freed, and the other is the propulsive force of the gunpowder. If this last force existed alone, it would project the ball in a straight line into space, whence it would not return. But, under gravity, there is a composite effect, as explained in a former chapter (Arts. 120, 158).

1036. In the composition of these two forces—the constant force of gravity, and the projectile impulse by which alone a body would fly off at a tangent—there may be a great variety of relative adjustments leading to a variety in the nature of the curves described. But the possible curves under the law of gravitation are limited to four,—the circle and the three figures commonly called conic sections—the ellipse or oval, the parabola, and the hyperbola. The two last are not closed curves, whence a body moving in one of them will pass round the central body once and then retreat for ever. All the bodies that revolve round the sun as a centre and make successive revolutions, must move either in circles or in ellipses of greater or less eccentricity. The planets and the satellites move in ellipses not far removed from circles: no body is known to move in a perfect circle, which the ancients believed to be the course of all the planets. Most of the comets describe highly eccentric ellipses, while some have appeared, whose course was the parabola or else the hyperbola.

The nearest approach to a circle is made by the planet Venus, as is seen by the very small eccentricity of its orbit. The fact is more familiarly shown by comparing the least and the greatest distances of the planet from the sun—$65\frac{2}{3}$ millions of miles and $66\frac{2}{13}$ millions. The ellipse of Mercury is the most eccentric as compared with the other large planets; its least and greatest distances are 28 and 42 millions of miles. The orbit of Mars, from which Kepler discovered his second law, is more eccentric than any one of the six known to him, except Mercury. But he could not have discovered his law upon the basis of Mercury for want of observations. The Earth's ellipse has the smallest eccentricity next to that of Venus. The eccentricity of the moon's orbit is about the same as the planet Saturn's, which has a middle position among the planets in this respect. The least and greatest distances of the moon are 221 and 252 thousand miles. This amount is enough to lead to some considerable perturbations of its orbit, under the disturbing influence of the sun.

To produce a circular orbit, a body needs to be projected at right angles to the *radius vector;* and the rate of projection or velocity must bear a certain fixed relation to the mass of the central body and its distance. If the line of projection is not a right angle, one of the other curves will be described. If the velocity falls short of the rate for a circle, or if it rises above that rate, the curve will be an ellipse, provided the difference is not much; but with a very great increase of velocity it will pass into a parabola or a hyperbola.

1037. The variation of the orbit under different degrees of the supposed projectile force, otherwise called the *tangential* or *centrifugal* force or tendency (under the first law of motion), may be illustrated by the following diagram:—

C is the centre of a circle, and under a certain adjustment of centripetal and centrifugal forces, a planet would describe a circle. If, when the revolving body arrives at A, an additional forward impulse towards G were given, instead of driving the planet away altogether into boundless space, like a stone leaving a sling, there would be merely the conversion of a circular orbit into an oval, or elliptical one, more or less elongated according to the strength of the impulse. It is readily conceived that, immediately after the new impulse, the planet having greater centrifugal force, would take a course such as shown in 2, 3, or 4, external to the circular curve, C; while evidently at the same time the attraction of the central mass in C would no longer be acting directly across the orbit, but, as seen in the figure at G, would be an oblique force, pulling back or slackening the speed of the planet, and, therefore, lessening gradually its centrifugal force. The

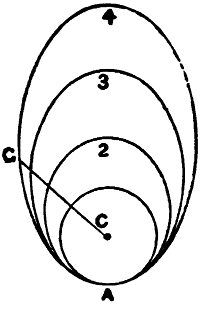

Fig. 314.

inward or centripetal bending would consequently be less opposed in the upper part of the oval, and the planet would soon become as a falling body, returning to A with quickening speed, to recommence the upward journey towards G in the ellipse (fig. 314). The speed lost in the ascent would be just balanced by the equal speed recovered in the fall, and although the velocity of the motion would be constantly varying, the time of performing the whole round would remain the same. When a body moves in an ellipse, under the influence of an attracting mass, this mass lies in the focus, F (fig. 315), and not in the centre, C.

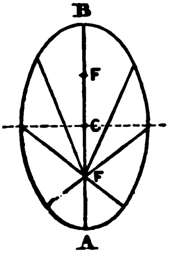

Fig. 315.

From the direction maintained by the Earth's Axis of Rotation, while circling round the Sun, there are produced the CHANGES OF THE SEASONS.

1038. There is one circumstance connected with the revolution of the earth round the sun which is of great importance to the inhabitants, although it might at first appear to be a matter of mere accident and indifference, namely, that the axis of rotation of the earth does not stand at right angles to the plane of its orbit round the sun. Let X represent the sun, supposed to be at a great distance (although here, for want of room, placed near), and let E N Q S represent the earth, N being the north, and S the south, pole of the axis, standing at right angles to E Q, the line of the equator and of the earth's orbit. Evidently, if the sun were in the direction, E Q X, his rays of light and heat would fall directly on the equator, and the sun would always appear to be directly over the equator. The nights and days would be of the same length of twelve hours, as indicated in this figure by the perfect correspondence of the illuminated and the shaded halves of the globe, and there could

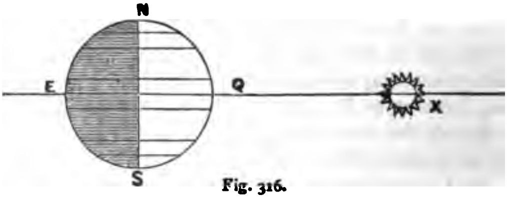

Fig. 316.

be no considerable change of temperature anywhere throughout the year.

But the axis of rotation, N S, is not perpendicular to the plane of the orbit, called the *Ecliptic.* As represented in figure 317, the north pole, N, leans 23½° towards that plane, and in the summer position for Europe, indicated here on the left hand, it is seen that the northern part of the globe is receiving much more sunshine than in the winter position, shown on the right hand. The upper and lower globes in the middle show that at half way between summer and winter, although the axis of rotation is oblique, the northern and southern halves of the earth share equally the light and shade. The figure exhibits also whereabouts upon the earth the days and nights are longer than twelve hours and where shorter.

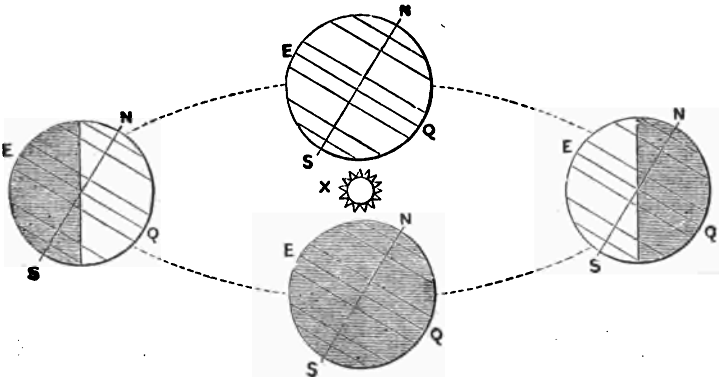

Fig. 317.

It might be expected that there would be a tendency in the rotating globe to change or rectify its position to that shown in the previous diagram, but there is no such tendency. There are a few slight and slow changes occurring in the direction of the earth's axis, to be explained under the heads of Precession of the Equinoxes and Nutation ; but they are of the nature of oscillating motions, which compensate or rectify themselves after a certain time.

> "*The Moon is a smaller globe revolving round the Earth, as the Earth revolves round the Sun.*"

1039. It has already been shown (Art. 1019) how to find out the moon's distance from the earth, and her real magnitude. The phenomena connected with her motions have now to be considered.

Of the many bodies in our solar system, the sun is the only one that is obviously self-luminous. The others, including the moon and all the planets, can affect our sense of sight only when reflecting part of the light which falls on them from the sun; just as is true of any common object in a landscape which in the darkness of night is quite invisible, but in the sunshine is beautifully bright.

It was the common belief of old that the moon also was self-luminous, a misconception which rendered the phenomena of the slender new moon gradually growing into the half-moon and full-moon, with the subsequent decline, so mysterious or inexplicable. No one then thought of making the experiment of suspending a ball near to a strong lamp in the external air of a dark night, and then walking round it, to see strikingly exhibited all the phases of the moon. The appearances are recalled by the adjoining diagram.

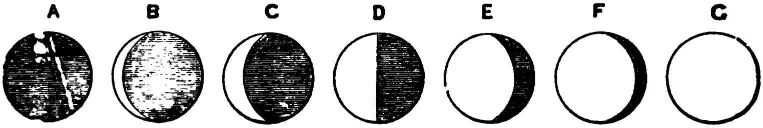

Fig. 318.

Nearly the same result is obtained by painting one-half of a globe white and the other half black, and then suspending it so as to cause it to rotate slowly before the eyes.

While the moon goes round the heavens daily with the sun and stars, it is also found to have a slower motion through the stars. Even in a few hours we can discern a change of its position among the stars, and between one night and another the shifting is very marked. At that rate, it passes the entire circuit of the stars in 27 days, 7 hours, and 43 minutes, which period is called a ***sidereal*** month or lunation.

This is not what is commonly called a "month," any more than the period of the earth's rotation is called a day. The proper month, as we understand it, is from new moon to new moon, or it might be from full moon to full moon. In the moon's motion round the stars, she necessarily comes once every circuit into the same quarter of the heavens as the sun, which is called being in *conjunction*. In that situation the face that is enlightened by the sun is turned completely away from the earth, and the moon is invisible to us. This is at new moon, A. In the course of two days a thin curved line of light is apparent, B; in three days and a half she reaches the octant, C, and appears "horned," as it is termed. In the second octant, she is in quadrature, D, and is then half enlightened. In the third octant, she is three-quarters enlightened, or "gibbous," E. The next octant is full moon, G; she is then in *opposition* to the sun. The second half of her course is a gradual decline in the inverted order, till by coming again into conjunction, she disappears.

Now the period of accomplishing this course is (in mean duration) 29 days, 12 hours, 44 minutes, and is our recognized month, technically called the moon's *synodic revolution.* The reason for its being more than two days longer than the sidereal month is that the sun likewise has advanced among the stars, so that the moon has to perform more than a complete sidereal revolution in order to be up with him. The sun performs almost one-twelfth of his annual course among the stars in thirty days; so that from one conjunction to another, the moon must go round the whole heavens once, and perform nearly a twelfth of a second circuit between one new moon, or one full moon, and another.

1040. If the moon's path through the stars were exactly the sun's path (as it appears to be), then at every conjunction the moon would overlie the sun, and cause an eclipse of the sun. Less obviously, but with equal certainty, at every opposition, the earth would lie in an exact line between the sun and the moon, and the earth, intercepting the sun's light, would make an eclipse of the moon. Now such eclipses do happen, but not every month. The track of the moon is not exactly coincident with the sun's apparent track, termed the *ecliptic.* The moon's track or orbit is slightly inclined to the ecliptic, the angle being a little more than five degrees (mean, 5° 8′; extremes, 5° 3′ to 5° 13′). It is thus possible for the moon to pass the sun without causing an eclipse. The sun in his annual course through the stars will approach and pass the places where the moon's orbit intersects or cuts the ecliptic, called the *nodes.* If the moon comes up when the sun is in one of the nodes, or within a little distance of the node, she will pass over the face of the sun, either wholly or partially, according to the sun's position. Of course, if the sun be exactly in the node when the moon comes up, there must be a perfect coincidence of the two. This is a comparatively rare occurrence. But an eclipse of the sun takes place, provided, at the time of the conjunction, the sun is within $13\frac{1}{2}°$ of the node, which gives a wide chance, although the farther from the node, the smaller is the eclipse. A lunar eclipse will happen if, at the time of opposition, the moon and sun are within 7° of the node.

In figure 319, let S be the sun, E, the earth, M, the moon given in two positions; one beyond the earth, and lying in the earth's shadow; the other, within the earth, and making its own shadow fall upon a small part of the earth's surface. In any part of the earth's shadow, the moon will be eclipsed totally, as often happens; if only partially within its shadow, there will be a partial eclipse. The sun is totally eclipsed only in a limited spot of the earth, and very rarely. Sometimes the cone of the shadow falls short of the earth, and then the eclipse is *annular*. To the spectators outside the *umbra*, or shadow, the eclipse is only partial.

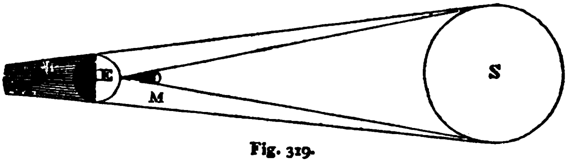

Fig. 319.

Every year there are two eclipse seasons, and, at least, one eclipse in each. Most commonly there are, each year, two solar eclipses and one lunar.

Many centuries before Christ, the discovery was made that, in a period of nearly nineteen years, the series of eclipses occurred exactly in the same order, so that they could be predicted beforehand.

1041. Unlike the earth, the moon spins very nearly upright as compared with the plane of her orbit. The deviation is only a degree and a half. The period of rotation of the moon is found to be precisely the period of her revolution round the earth. From this fact it happens that the same side is always turned to the earth, and consequently one half of the surface is permanently hidden from our view. There are various circumstances that extend the visible portion, so that, at one time or another, nearly six-tenths of the surface may be seen. The extension of view thus caused was first observed by Galileo, and has been designated the Moon's *Libration* or swinging. These circumstances are easily explained.

For one thing, the rotation of the moon is constant and equable, while the pace of revolution varies; whence the two motions do not exactly coincide. If we suppose the angular motion of revolution somewhat slower than the average, then the rotation gets ahead, and brings round into view a small portion that would be hidden if the two motions were coincident. When the revolution is above the average, the rotation seems to lag, and so exposes to view an extra portion on the other limb. In this way an extension of visible surface is gained, amounting in all to 7° 45′, which is called the Libration in *Longitude*.

Again, as the axis of rotation is not perfectly upright, the two poles are alternately visible from the earth, whence the circumpolar surface is visible all round for a little way. This is Libration in *Latitude*, and amounts to 6° 44′.

A small additional extension of visible surface is gained through the variation of the observer's position by virtue of the rotation of the earth. The greatest amount of this corresponds to the moon's parallax, which is almost one degree. It is called *Diurnal* Libration.

By the aid of the telescope the moon's visible surface has been mapped out in minute detail. The blotched and variegated appearance is resolved into an alternation of plains and mountains; the darker patches are plains, of greater or less extent, surrounded by mountains, whose shadows are seen when the sun shines obliquely on them as at new moon. These enclosed plains, or hollows, are of very various sizes, but all of one type, corresponding to our volcanic mountains. There is always a cup, or crater, surrounded with mountain walls, and often a conical peak in the centre. According to the degree of deviation from a level surface, the depressions are denominated Walled Plains, Ring-mountains, Craters, and Holes. Among the craters the most remarkable is that named "Tycho," which is a circular enclosure forty-seven miles across. The inner side of the surrounding ridge is a steep mountain-wall, sixteen thousand feet high, while the height outside is only twelve thousand feet, showing a depression below the surface of four thousand feet. In the centre of the enclosed plain, or hollow, is a cone five thousand feet high.

There are few of what we term mountain ranges. The most conspicuous is named the Apennines, a chain of four hundred and fifty miles in length, one of its peaks rising to eighteen thousand feet. Several mountains exceed twenty thousand feet.

Although the structure of the moon's surface is apparently volcanic, there are no traces of volcanoes in a state of activity. The whole surface is dead and fixed. There is no water, and nc atmosphere; consequently living beings do not exist. There may have been originally the same gaseous elements as make up our air and water, but being too small in quantity they have been all absorbed into the solid mineral compounds.

The illuminating power of the full moon has been estimated at about one six hundred thousandth part of the sun's light. While there is this amount of reflected light, the most delicate thermoscopes have failed to show the emission of heat.

MECHANICAL LAWS OF THE MOON'S MOTIONS.

1042. In describing the mechanical principles of the earth's revolution round the sun, as determined by the two forces—central attraction and a tangential impulse—the case of the moon's revolution about the earth was included; the forces being exactly the same, with the difference in the central body, which is, in the one case, the sun, and, in the other case, the earth. If no extraneous power were at work, the calculation of the moon's place would be determined according to Kepler's laws, with the sole qualification, not known to Kepler, namely, that the centre of the moon's revolution is not the centre of the earth, but the common centre of gravity of the earth and the moon. This is known from the relative masses of the earth and moon; it is nearly three thousand miles from the earth's centre, or nearly one thousand miles beneath the surface.

But the moon is not left solely to the attraction of the earth. According to the theory of Universal Gravitation, every body attracts every other body; yet, since the amount of attraction varies directly according to the mass of the attracting body, and inversely as the square of the distance, a body that is either very small or very distant from another, may be left out of account. The disturbance of the moon by the stars is practically nothing; the disturbance by the other planets is trifling; but the effect of the sun is so considerable that to neglect it would involve very large errors. The Lunar Theory consists in explaining the various modes of deviation from the elliptic path caused by the sun.

1043. In the first place, the effect upon the moon of the sun's attraction as a whole is to counteract or lessen the gravitating force ot the earth. For, if the moon is on the same side of the earth as the sun (that is, in conjunction), the sun's attraction draws her away from the earth by a certain fixed amount; and when the moon is in opposition, or on the side of the earth away from the sun, the sun attracts the earth more than it does the moon, and still widens the interval between them. At the quarters or quadratures, the sun's tendency is to draw the moon towards the earth, or to add to the central attraction; this effect, however, being much less than the other, so that, on the whole, the sun's influence operates to counteract the earth's attraction. Now, if the earth's path around the sun were in a circle, the earth would be always at the same distance from the sun, and the reduction of the earth's gravitation, as far as the moon is concerned, would be a constant quantity, and would come to the same thing as if the mass of the earth were smaller than it is. As regards the computation of the moon's motions, it could be left out of account. But the elliptic orbit of the earth makes the influence more powerful at one time than at another, and the effect is to produce a yearly disturbance in the moon's rate of motion. Any diminution in the earth's attracting power makes the moon's motion slower; hence, when the sun is nearest the earth (which is in winter) the lunar month is slightly increased. The greatest amount of this displacement, as compared with the mean motion, is about one-fifth of a degree in angular motion (11′ 12″), or in time about twenty-four minutes. This disturbance is called the yearly or *Annual Equation.*

A second variation is due to the inequality of the sun's action in the course of the moon's revolution. As already stated, in conjunction and in opposition, the sun lessens the effect of the earth's attraction; in the quadratures it increases it. But, farther, we must look at the sun's action *at right angles to the radius vector*, which action is at its maximum in the quadratures. On that side of the orbit, when the moon is moving nearer the sun, its velocity will be increased until it reaches the line of conjunction; when it passes this line, and moves in the opposite direction, it will be steadily retarded until it reaches the point of opposition. The deviation of the moon from what would otherwise be her position may in this way amount to upwards of half a degree, or more than her own breadth. To this disturbance is given the title *Variation.*

A third inequality is one due to the eccentricity of the moon's orbit; it would not exist if the moon moved in a circle. It is plain that the sun's attraction must vary according as the moon is at its nearest or its greatest distance from the earth—called respectively the *perigee* and the *apogee.* The effect of this disturbance is represented as making the moon's ellipse wheel round in the same direction as the moon herself revolves. The extent of the disturbance is such that the orbit performs an entire revolution in nine years, but not at a steady pace. This is the revolution of the line of *apses.* The inequality is termed *Evection.* In amount it is such that the moon's place may be affected to the extent of nearly three diameters (1° 20′).

The eccentricity of the moon's orbit is itself disturbed at the same time, being sometimes above, and sometimes below the average, to the extent of one-fifth of the whole. The mean distance of the moon from the earth is not disturbed from the same cause.

The foregoing inequalities would all occur although the sun, earth, and moon were always in the same plane; that is, if the moon's orbit round the earth coincided with the earth's orbit, or the ecliptic. But as the the moon's orbit is inclined to the ecliptic at or about an angle of 5°, the sun exerts a new kind of disturbance—it pulls the moon, as it were, back to the plane of the ecliptic; the effect being to accelerate its crossing the plane, or to make it cross on each occasion sooner than it ought to do, that is, before it has got round an entire half-circle from the last crossing. This is represented as making a revolution backwards of the *line of nodes.* The retreat of that line is at such a pace that it completes its backward circle in about nineteen years. The great importance of this period consists in its determining the recurrence of eclipses in a regular series.

While the line of nodes has its regular backward course, the inclination of the orbit is varied to the extent of about 8′.

The Tides.

1044. The nature of the tides, as a matter of fact, is well known. All over the ocean the water rises and falls on the coasts twice in rather more than twenty-four hours. Kepler observed that there was a coincidence between the tidal periods and the positions of the moon, and Newton supplied the mechanical explanation.

In the phenomenon of the tides there is this paradoxical fact, that while on the side of the earth where the moon is seen, the water rises towards her, making there a flood tide of many feet in depth, on the opposite or distant side of the earth, away from the moon, the water similarly rises to an equal height. The fact is pictured in the adjoining diagram. M is the moon, B A the earth, and the protuberances of the water at A and B are the flood-tides in both situations at the same time. Thus, although the moon appears over any part of the earth only once in twenty-four hours, the flood-tide occurs there twice. The explanation of the tide at B on the side of the earth towards the moon offers no difficulty, and the tide at A on the distant side of the earth is the effect of the centrifugal force of the water at A not fully balanced by the attraction of the moon, which is nearly 8000 miles more distant from A than from B.

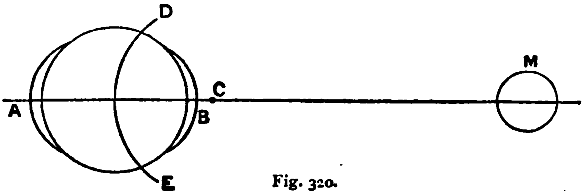

Fig. 320.

The tide on the near side, therefore, may be called the *centripetal* tide, and the other the *centrifugal.* It is also to be remarked that when there is an accumulation of water or flood-tide on two opposite sides of the earth, there must be a deficiency of water, or ebb-tide, on the intermediate parts. It was explained in a former page (116) that when two mutually-attracting or cohering bodies are revolving round each other they both really are revolving round the common centre of gravity of the two, here marked C.

The sun also produces tidal disturbance in the waters of this globe, but not nearly so great as that made by the moon, because of the vastly greater distance of the sun. When, however, the two influences either join or are in direct opposition, the stronger effects are produced called the *spring-tides* and the *neap-tides.*

If the earth were all covered with ocean, the two tidal waves would rise and subside uniformly all round it, but owing to the irregular forms of the land and of the sea-bottom, the simple progress is prevented. A striking phenomenon connected with the tides is, that when the great tidal wave enters a broad inlet or bay which gradually contracts towards the inner end, as in the Bristol Channel, such wave becomes higher as it is compressed by the narrowing channel—in some places to the depth of nearly 100 feet.

as in the Bay of Fundy, in North America. Into the mouths of the Ganges, below Calcutta, the tidal wave often enters with steep front and great violence, forming what is called the *bore*, and causing great commotion among the boats and shipping in the river. In the silence of the night sometimes a person may hear the distant sound of the incoming flood, and may feel surprised to reflect that the apparently small moon, looking down from a calm sky, is really the cause of the uproar in the gulfs and rivers.

Precession of the Equinoxes.

1045. It has been seen that the changes of the seasons are due to the fact that the earth does not spin upright; its equator (the plane of its rotation) is not the same as the ecliptic, the plane of its revolution. The two are inclined at an angle of 23½°, called the angle of the obliquity of the ecliptic. The points where the circle of the ecliptic is cut by the plane of the earth's equator are of great importance in astronomy. They are the places where the sun lies at the time of the equinoxes. They are also the land-marks for determining the localities of the stars, as regards their east and west positions (*longitude* when measured in the ecliptic, *right ascension* when measured in the equator). The starting-point is the sun's place at the March or vernal equinox. Now, a comparison of ancient observations shows that the measured places of the stars have undergone a steady change; their longitudes, or distances from the spring equinox, have all increased. Since the time of Hipparchus, about two thousand years, the increase has amounted to about a twelfth part of a circle, or a sign of the zodiac. It amounts to 50 seconds of a degree annually, or a degree in 71½ years.

The effect would obviously arise, supposing the equinoctial points were to retreat at the rate indicated: the stars are where they were before, but the point of reckoning is moving backwards, or from east to west. This fact is called the *Precession*, or *anticipation* of the *Equinoxes*. The equinox does not fall at the same solar position one year as it did the previous year, but is in advance, according to the rate above given. The nodes, or crossing points, are not fixed, but shifting, and make a circuit of the entire heavens in about 26,000 years.

1046. The fact had long been known, but there was no explanation given of it, until Newton's discovery of gravitation, of which it is one of the many far-reaching consequences. It is a disturbance of the earth's rotation by the combined attraction of the sun and the moon, directed upon the equatorial bulging.

If the earth were perfectly round, precession would not happen. It is the ring of solid matter that surrounds the equator that is disturbed, as if it were a satellite going round the earth in an orbit inclined to the ecliptic. The disturbance is of the same character as that particular disturbance of the moon's orbit arising from its inclination, and has the same result, namely, a retreat of the nodes, or points of intersection of the two planes.

If the earth had no rotation, and if it were, nevertheless, bulged at the equator, the attraction of the sun and moon upon this bulging would reduce the inclination of the two planes ; the equator would become parallel to the ecliptic. But this effect is not produced upon a rotating body ; the inclination of the axis is not disturbed ; just as a spinning-top does not fall on its side, although it spins slantingly. The real effect is best conceived by the supposition of a revolving satellite in an inclined orbit, as the moon. Such a body under a disturbing influence, so directed that part of it is perpendicular to the plane of the ecliptic, is brought precipitately down to the ecliptic, instead of pursuing its course until it reaches the exact point of the previous crossing.

1047. Superadded to the precession, is a secondary disturbance, called the *nutation* of the earth's axis, which causes, in the motion of the nodes, a fluctuation having a short period. As the great disturbing agent in precession is the moon, and as her tendency is to make the nodes retreat in her own plane, and not in the ecliptic, the actual precession is a combined phenomenon ; it is governed in part by the retreat of the moon's plane upon the ecliptic ; and as this follows a period of nearly nineteen years, the deviation induced by it will have the same period. It was observed by Bradley that the declinations (distances from the celestial equator) of the stars increased for nine years, and then decreased for nine years following, the maximum being 18 seconds of a degree. This, therefore, constitutes a farther correction to be made to the observed places of the stars, in order to obtain their real places.

SECTION V.

The earth is the third, as to distance from the sun and as to length of year, of a series of like globes, called PLANETS, *which are very various in size, some larger, some smaller, than the earth. There also revolve round the sun other masses, very peculiar in their character, called* COMETS.

1048. The adjoining diagram will give a general notion of the arrangement of sun and planets, which constitute what is called the SOLAR SYSTEM. It represents what an eye would see if looking down on the system from a great elevation on its north side. The central figure marks the place of the sun, and the numbered circles around it indicate the paths or orbits of the different planets moving in the direction shown by the arrows, as they would appear if every planet left a line of light where it passed along. The nine chief planets have their orbits here numbered. The following fanciful names were early given to them from the heathen mythology, and although without distinct meaning, are still retained :— 1, Mercury ; 2, Venus ; 3, the Earth ; 4, Mars ; 5, a crowd of smaller bodies called planetoids, like parts of a large planet not yet cohering ; 6, Jupiter ; 7, Saturn ; 8, Uranus ; 9, Neptune.

All these bodies are in form globular, proving that the law of gravitation, which accounts for the form of the earth, as explained in a former section, is active throughout universal nature. And they are all restrained in their orbits by the same balance of centripetal and centrifugal forces which rules elsewhere.

1049. The Sun, as already stated, is the only self-luminous body in the system, and, therefore, the most important in it. The sun's presence makes day, its absence night ; its more direct beams make summer, its less direct make winter ; and on its numerous influences depend the life and well-being of the animal and vegetable creation.

Thinkers have speculated on the probable mode of origin of this glorious system, inquiring whether it may have come into existence at once, nearly as we now see it, by the will of its Divine Author, or whether, like all the subordinate objects, of which men may witness the beginning, it was built up gradually by successive additions of minute particles, in obedience to laws which Divine Wisdom had ordained.

The most majestic oak now standing in any forest was once only a small acorn or seed ; the whale, the elephant, the lion, and even

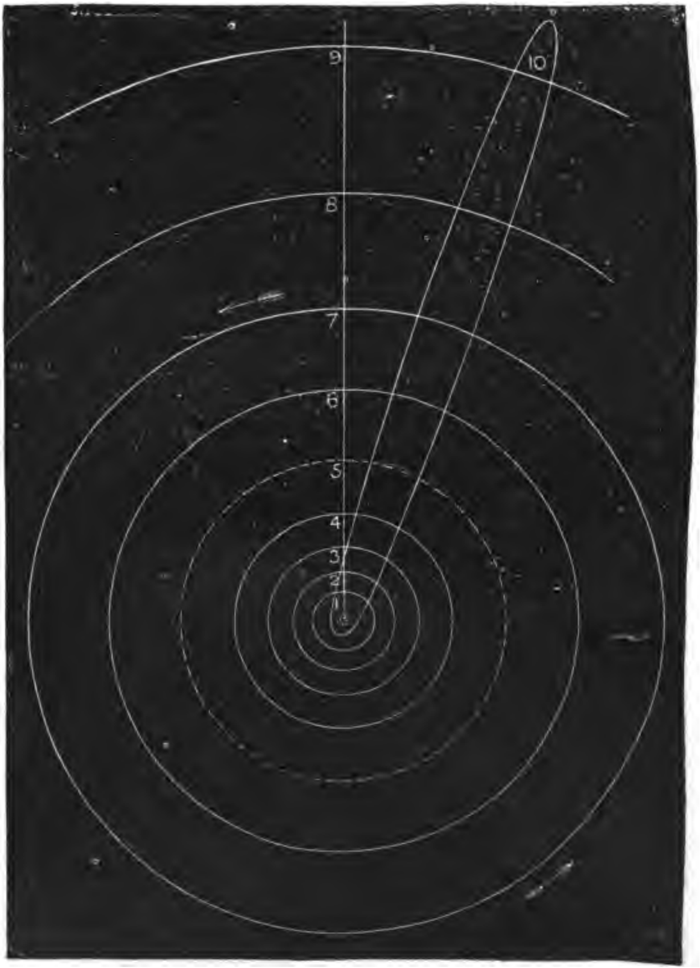

Fig. 321.

every human being now existing in the world, commenced visible existence as a minute ovum or embryo, which has been gradually built up to the dimensions of maturity by atom joined to atom.

It is known that all the elementary substances of which larger masses in the world are formed, namely, the metals, carbon, sulphur, and the rest, are resolvable by strong heat into a gaseous or aëriform condition, invisible to human sight; so that this solid globe, and all within and upon it, might, by heat, be changed into a vast transparent mass. We may adduce as illustration of this truth the phenomena now to be described.

Any person looking up into a perfectly transparent sky, may see there nought but bluish space or extension, although aware that the space is occupied by a material atmosphere. A change then occurring in the temperature, or electrical state of that atmosphere, may suddenly cause a haze to appear. The moist particles of the haze may then multiply and become a dense cloud, and that moisture may soon condense, or coalesce, into drops of rain; these, with increase of cold, may be frozen into solid snow-flakes or hail-stones, which mutually cohering into larger masses, and descending with violence to the ground, can demolish any fragile objects, and may even kill animals of considerable size. If the atmosphere during such changes have a vorticose motion as in the whirlwind or cyclone, the solid masses must share in such motion.

If something like this solidification of gaseous invisible matter had occurred long ago on a prodigiously larger scale, planets instead of hail-stones might have resulted, and the present solar system might have come to occupy the space previously held by the transparent cloud. Such a supposition would seem to explain why all the planets, and all the satellites about the planets, revolve in the same direction, and why the individual planets, and even the sun himself, rotate about their own centres in that direction, and further, it accounts for the very remarkable fact that in the wide space between the two planets Mars and Jupiter, where, to maintain uniformity of condensation throughout the space, a larger planet should have appeared, but did not, the improved telescopes of modern times discover a great number of smaller masses revolving, which, if united, would form such a planet as seemed due to the situation.

1050. This sketch is presented, not as the history of the origin of the solar system, but, by analogy, as a familiar type, in order to facilitate the conception of the great facts really existing.

The invention of the telescope and other valuable means of observing facts, and the improved modes of computation devised in recent times, are by no means opposed to some such origin of the solar system as that above sketched.

Table of the great bodies of the Solar system, with their sizes, distances, and other particulars.

PLANETS.	Mean *distance* from the SUN in Millions of miles.	*Bulk* as compared with this Earth.	Time of *Rotation* or length of DAY.		Time of *Revolution* or length of YEAR.		Number of Moons
			HRS.	MIN.	YRS.	DAYS.	
Mercury .	$35\frac{1}{3}$rd	$\frac{1}{17}$th	24	$5\frac{1}{2}$?	0	88	None.
Venus . .	$66\frac{2}{13}$ths	$\frac{17}{20}$ths	23	21 ?	0	$224\frac{7}{10}$	None.
Earth . .	$91\frac{1}{2}$	1	23	56	0	$365\frac{1}{4}$	1
Mars . .	$139\frac{1}{3}$rd	$\frac{1}{6}$th	24	37	1	$321\frac{3}{4}$	None.
Planetoids.	200 to 315	—	—		$3\frac{1}{2}$ to 7 yrs.		—
Jupiter. .	$475\frac{2}{3}$rds	1233	9	$55\frac{1}{2}$	11	$314\frac{1}{4}$	4
Saturn. .	$872\frac{2}{13}$ths	696	10	$29\frac{1}{4}$	29	167	8
Uranus .	$1,753\frac{7}{8}$ths	74	9	30 ?	84	6	4
Neptune .	2,746	105	—		165	110	1
Moon . .	from Earth 238·818 miles.	$\frac{1}{50}$th	27 d. $7\frac{1}{2}$ h.				
SUN . .	—	—	25 days.				

In thinking of the stupendous magnitudes and relative distances of the bodies which constitute our solar system, it facilitates the conception to figure before the mind an arrangement exhibiting nearly the like proportions on a vastly smaller scale, among known things. Thus, if a Londoner imagines a globe, of about eighty feet in diameter, placed on the summit of St. Paul's Cathedral, to represent the sun, the comparative distances and magnitudes of the planets would be roughly as follows :—

Mercury,	a globe of	5 inches	diameter at Putney.
Venus	.	11 inches	. Richmond.
The Earth	.	12 inches	. Windsor.
Mars	.	9 inches	. Oxford.
Jupiter	.	10 feet	. Liverpool.
Saturn	.	7 feet	. Durham.
Uranus	.	6 feet	. Edinburgh.
Neptune	.	5 feet	. Orkneys.
Our moon	.	3 inches	. 30 feet from the Earth.

It is a matter of pure arithmetical computation that a railway train at a uniform speed of forty miles an hour would need nine months to reach the moon, three hundred years to reach the sun, and a thousand times as much to reach the nearest fixed star.

One is surprised to think how small a portion of the space of the universe is occupied by the substance of the sun and the worlds around him.

THE SOLAR SYSTEM.

The Sun.

1051. The Sun, the central attracting body of the solar system, and the source of heat and light to all its members, is a vast globe. It exceeds the earth in diameter more than one hundred times; in volume, a million and a quarter times; and, in mass, nearly one-third of a million of times.* The reason why the mass is comparatively less than the volume is, that the density or specific gravity of the sun is only one-fourth of the earth's density. Still the mass of the sun exceeds by six hundred and fifty times the mass of all the planets taken together. The sun rotates on its axis like the earth; each revolution takes twenty-five days.

The intensely brilliant surface has long been known to contain dark patches or *spots*. These do not remain constant—they come and go. They may be very numerous, and they may be very large. One was observed by Sir W. Herschell whose diameter exceeded fifty thousand miles.†

Around the dark spots, and in other places, there are brighter streaky portions called *faculæ*. These also are constantly changing their shape.

The spots are generally seen to consist of a dark central part or nucleus, called the *umbra*, and a less dark surrounding fringe, called the *penumbra*. Their forms are very irregular. They are all subject to one steady change of position and appearance, which has been interpreted as due to the rotation of the sun, and was the means of discovering and estimating that rotation. The changes in their own nature relate to the manner of their appearance and disappearance, which are both gradual; the umbra and the penumbra increasing and diminishing together.

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* The enormous size of the sun may be estimated from this fact. One half of its diameter (426,450 miles) would be nearly equal to twice the distance of the moon from the earth.

† The spots were first discovered by Galileo in 1610.

It is found that the sun's surface passes through a regular period of spot-development, from the extreme of total absence of spots, to the extreme of maximum abundance. This period is about eleven years. The spots are undoubtedly associated with magnetic disturbances in the Earth. Likewise, they seem to vary with the positions of the planets Mercury, Venus, the Earth, and Jupiter.

Some other singular features connected with the sun's disc have of late years been observed when the sun is under a total eclipse. At the moment of totality there is seen around the sun a vast halo of silver-bright light. It has a radiated structure, and extends to a great distance, sometimes as far as the breadth of the moon's diameter. These are in addition to rays called aigrettes, that seem to shine through the continuous halo. This halo has been designated the *corona.*

Besides the corona itself, with the aigrettes, there have been observed, close to the edge of the moon, and within the corona, peculiar red prominences of various and fantastic shapes. They are very numerous, and are classified into jets—single, grouped, and ramified; columns or pyramids; and cloudy waves. These are named *prominences* or *protuberances.* Like the spots, they come and go; and from their magnitude and rate of change, indicate matter in motion at an enormous velocity.

1052. Such is a brief outline of the solar peculiarities. Their explanation, so far as yet made out, is connected with the general view now taken of the sun's exterior. The body or mass of the sun is believed to be a comparatively dark solid; on this floats an immense ocean of fluid matter, which contains the light-giving ingredients—the luminosity being connected with the enormously high temperature of the sun's surface and body.

The ocean, or atmosphere, or fluid environment of the sun, has been distinguished into several parts or layers. Chief of these is the more exclusively luminous layer, called the *photosphere,* or the light-surface or shell. This is a mass, perhaps thousands of miles in depth, of intensely heated matter: it is the solar surface as we see it, and the chief source of both light and heat. The spots are breaks or openings in this luminous stratum, through which is seen the darker surface of the sun. Being fluid, and exceedingly hot, it is believed to be in a state of incessant agitation, so as now and then to open up and leave comparative darkness for a time; the opening and the closing being very rapid, although gradual.

The white-hot material of the photosphere does not exhaust the solar envelope. There is reason to suppose that this material lies in a more extended atmospheric mass, with but little luminosity.

Above the photosphere is a gaseous stratum named (by Lockyer) the *chromosphere.* It has luminosity, but in a very inferior degree; it is reddish, and it is the base and source of the red flames and prominences seen in eclipses. It is known to rise to a great height above the photosphere (many thousands of miles).

The chromosphere shades off into an upper stratum, less luminous, which is the *corona*, or coronal atmosphere, as already described from its appearance in eclipses.

The materials or substances composing the envelope of the sun have been discriminated by means of the spectroscope. Among these are *hydrogen* gas, and the vapours of the metals, *magnesium*, *calcium*, *sodium*, *iron*, *chromium*, *manganese*, *nickel*, *barium*, *strontium*, and *titanium.* There may be many others, and it is supposed that there are among them some substances that are not found in the earth. The metallic vapours, at a white heat, constitute the photosphere. In the chromosphere, the prevailing substance is hydrogen, at such a temperature as to make it luminous, although not to the degree of the metallic vapours. Above this luminous hydrogen is the same gas in a cooler and less luminous condition, together with another substance not existing in the earth, to which has been in the meantime given the name *helium.*

1053. The enormous changes, indicated by the spots and prominences, show the intense activity of the solar atmosphere. The hypothesis at present adopted to explain the nature and direction of the activity or movements, is a system of up-and-down-currents, or upheavals and sinkings, accompanied with whirling or cyclonic motions. The upheavals are sometimes so violent as to be compared to volcanic eruptions. A mass of heated matter is forced up from the photosphere below, and leads to an upheaval in the chromosphere above. The rise of photospheric matter makes the bright spots or *faculæ*, the further upheaval of the chromosphere makes the jets or prominences. These are proved by the spectroscope to be, in many instances, cyclonic; and this is probably the case with them all. Corresponding to the upheavals there must be down-draughts or currents from the (comparatively) colder heights, which would make the dark openings of the photosphere known as the sun's spots. These downward currents may also be presumed to be cyclonic.

Estimates have been made of the rapidity of these eruptive up heavals. Counting the time of throwing up prominences to a measured height, the rapidity of movement of the gases is sometimes not less than 120 miles a second.

Considered merely as a hot body parting with its heat and light through incessant radiation, the sun must in course of ages cool down, so as no longer to maintain the present temperature of the planets. For a very long time, no appreciable difference may be felt, but too little is known to enable an exact estimate to be formed of the rate of diminution.

The Planets.

1054. *Mercury.*—A small planet, and the nearest to the sun; it seldom obtains a sufficient elongation to be seen, being hidden in the solar rays. The mean distance from the sun being about one-third of the earth's distance, the intensity of the sun's heat and light must be nine times as great as on the earth, which would bring about a temperature incompatible with life as known to us. Mercury goes through phases like the moon.

From the intense brilliancy of the surface, there is an absence of the discriminating marks that give information as to the planet's period of rotation. From such indications as could be had, it has been inferred to rotate on its axis once in about twenty-four hours. The existence of an atmosphere has not been determined.

1055. *Venus.*—The morning and the evening star. In size and density, Venus nearly resembles the earth. The distance from the sun (sixty-six millions of miles) is rather more than two-thirds the earth's distance, the heating and lighting power of the sun being thus fully double that on the earth. The equatorial heat would be excessive, judging from our standard, but the neighbourhood of the poles would contain climates resembling some of the habitable parts of the earth.

The rotation of the planet is very nearly the same as the earth's; but the inclination of the axis is very much greater, being supposed to be about 50°. This entails an enormous difference of the seasons, which would operate unfavourably upon life. There are appearances that indicate an atmosphere, and mountains, but not very decisively. Recent spectroscopic obversations are in favour of the presence of water, which would imply an atmosphere.

The different positions of Venus make her distance from the earth very unequal, so that she varies greatly in apparent size. The accompanying diagram, taken from photographic representations, shows both the variation of apparent size, and the phases of the planet.

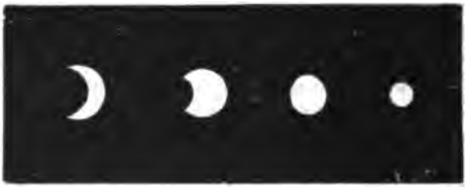

Fig. 322.

1056. *The Earth.*—Next in order from the sun is our earth. What we do not know about the other planets, or know by precarious inference, we know with ease and certainty about the earth. Yet, in its planetary character, there are some things that we do not discover with the same directness as in the case of the planets commonly so called. Placed as we are at a distance, in their case, we can discern at once their round shape, and their motions through space.

The first property of the earth, considered as a planet, is its Figure. It is nearly, but not exactly, a globe. It is flattened at the poles, and it bulges at the equator; the difference of the two diameters, as already stated, is twenty-six miles, or about one three-hundredth part. The equator itself is not a perfect circle, there being a difference of about two miles between its longest and its shortest diameter.

The form and size of the earth being ascertained, the next important fact is its Density considered as a whole. We know the density of the materials composing the crust, so far as we are able to penetrate it. The rocks that are accessible to us have a specific gravity of between two and three, water being one. But these superficial rocks may not represent the interior. In the depths there may be a great quantity of the heavy metals, as iron, lead, copper, tin, silver, gold, and their prevalence in any considerable proportion would raise the average specific gravity much above the specific gravity of the ordinary rocks. Moreover, we do not know the limits to the condensation of bodies under hundreds of miles of a superincumbent mass, although probably the utmost amount of compressibility of the ordinary minerals is not great.

The difficulties of ascertaining the mean density of the whole earth, so as to estimate the quantity of matter contained in it, are very considerable. Different methods have been resorted to.

The most direct method is to measure the deviation of a plumb-line from the perpendicular, when in the neighbourhood of a large mountain. If this deviation (which is a very small quantity) could be accurately measured, and if the mass of the mountain (combining its bulk and its specific gravity) could be measured, we could deduce the mass of the earth. This operation was performed in the last century, in Perthshire, by Dr. Maskelyne, and is called the "Schehallien" determination. By it the mean density was given at between 4·56 and 4·87

Another method is the Cavendish experiment by the torsion balance, a far more delicate apparatus for testing attraction in small amounts. Instead of a mountain, which, although from its size it is able to exert a considerable influence, is very difficult to measure, Cavendish substituted two heavy spheres of lead, which were brought into the neighbourhood of the little balls at the end of the torsion lever. The joint attraction of the spheres deflected the balance, and the amount could be measured and compared with the downward gravity of the earth. The result was to make the density of the earth as a whole 5·48. The same experiment, repeated since with still more care, has since given 5·66 as the figure.

The third method, called the pendulum method, is carried out in two forms. In the one, a pendulum is taken to the top of a mountain, and the swing compared with what it would be (known by calculation) at the same height above the unelevated surface of the earth. On the other method, the pendulum is taken to the bottom of a deep mine. In such a spot, attraction is diminished, in so far as there is less matter to attract (the portion overhead counts for nothing), and increased in so far as the attracted body is nearer the centre of the earth. The last effect is the greater of the two, and the gravity is actually increased, as shown by the increased rate of vibration of the pendulum. By this method, which was carried out under the direction of the Astronomer Royal, Sir George Airy, in the Harton Colliery, South Shields, at a depth of 1260 feet, the calculation showed a density of six and a half times water, or 6·565. The previous estimate is still preferred, and it is usually assumed that the average density of the whole earth is 5·6.

This determination is the key to the estimate of the densities of all the other bodies of the system. The *comparative* masses of the sun, planets, and satellites, are found by their relative gravitating energy. But we cannot tell the *absolute* masses till some one is estimated, and this one must be the earth. The earth's density multiplied by its bulk gives its mass or quantity of matter.

1057. The distance of the earth from the sun is ascertained on the principles already described in Art. 1020. It is measured by means of the angle of horizontal parallax; which, however, is so small that errors greatly affecting the result may easily be made. The earth's semi-diameter as seen from the sun, amounts to less than nine seconds of an arc.

It is for this determination that so much importance is attached to the TRANSITS OF VENUS across the sun's disc, which occur at alternate intervals of 8, 122, 8, 105, 8, 122, years. Two occurred near the middle of last century (1761, 1769); from them the conclusion was drawn that the parallax of the sun is between 8″·5 and 8″·7. From this was obtained the estimate of the sun's distance that long prevailed, namely, 95 millions of miles. The next transit occurred in 1874; but in the meantime other methods have led to the adoption of an increased angle of parallax, and consequently a diminished estimate of the sun's distance.

The method of proceeding for the transit of Venus consists in choosing two stations in the earth as widely as possible apart in latitude, or north and south, and as nearly as possible in the same longitude. The difference of the position of the observer will make a difference of position in the projection of Venus in the sun. The design is to measure exactly the interval of the two apparent tracks, which is done in a very efficacious manner by the difference of *time* of the apparent transits. The transit that is nearest the sun's centre will be longest from the nature of a circle; and from the difference of time, the difference of the two projections can be known.

In the diagram let S be the sun, E, the earth, and V, the planet Venus, supposed to be in line with the earth and the sun, and

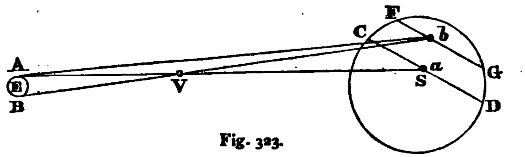

Fig. 323.

thus casting its shadow on the sun's disc. Let A and B be two stations in the earth as far asunder as possible in the north and south directions and as near as possible in the same meridian. From A the planet Venus is seen crossing the sun in the line, C *a* D; from B the apparent crossing is F *b* G, farther from the centre, and therefore shorter in length and in duration. The business of the observers is to ascertain with the utmost accuracy the moment of time when Venus touches the edge of the sun, and also the moment of leaving the other edge, with a view to get the precise duration of the transit. This being known, enables us to say at what distances from the centre of the sun the two apparent transits took place; whence can be ascertained the distance (in angular measure) between C *a* D and F *b* G. That distance is the angle, *b* V *a*, at Venus, and is not the angle that we are in quest of, but is a stepping-stone to the real determination. It must be premised that the *proportionate* distance of the earth and Venus from the sun is known. Supposing Venus were exactly half the distance of the earth, the angle, *a* V *b*, would be found to be double the angle, A *b* B, the real parallax sought, namely, the angle at the sun, subtended by the distance of the two stations, A and B. As Venus is more than half the earth's distance from the sun, the known proportion of the two distances, A V and V *b*, will enable the angle of parallax, A *b* B, to be calculated.

The distance of the two stations being known, and the angle of parallax corresponding, the sun's distance is deduced. Or we may ascertain what would be the angle corresponding to the earth's semi-diameter, which is the proper angle of the sun's horizontal parallax.

1058. Another method, considered by some astronomers to be more exact than the Transit of Venus, is to reason from a certain inequality in the moon's motions, called the *Parallactic Inequality.* This method makes use of the ascertained distance of the moon; and as the inequality depends upon the proportion of the sun's distance to the moon's, it furnishes a means of computing the sun's distance, the moon's being known. By this method, a parallax was obtained amounting to 8″·9159.

The amount at present adopted, from which the sun's distance (91,430,000 miles) and all the elements of the solar system have been calculated, was agreed upon by Airy and Le Verrier, namely, 8″·94. It is thought that this may have to be reduced one-fiftieth of a second, to 8″·92. The sun's distance would then be about 91⅝ millions of miles.

1059. *Mars.*—The nearest to the sun of the planets beyond the orbit of the earth, called the *superior* planets. Its distance (mean) is nearly one hundred and forty millions of miles. The heating power of the sun at this distance is less than half what it is on the earth ; so that while the equatorial climate might be endurable by us, the poles would be cold in the extreme. The length of the day and the changes of the seasons are nearly the same as with us.

The appearance of the surface is reddish ; but it is so plainly variegated, that inferences can be drawn respecting the constitution of the planet. At the poles there is a dazzling whiteness, always supposed to be snow ; the extent of the white surface varying with the seasons. In other parts, the alternation of light and dark tracts is supposed to indicate land and water. If so, the proportions are the opposite to what we find on the earth ; the land being four times the extent of the water.

The presence of an atmosphere is fully established. The spectroscope attests the existence of watery vapour.

1060. *The small planets.*—The length of the interval that separates Mars and Jupiter often suggested the idea that some planet circulated between the two. On the first day of the present century a planet was discovered, so small that it could never be seen by the naked eye. When its orbit was ascertained, it was found to occupy the blank. In fact, it curiously fell in with a regular law of progression that had been observed in the distances of the planets (called Bode's law). The only anomaly about it was its utterly insignificant size ; for although the other planets show great differences of size, between the extremes of Mercury and Jupiter, yet, as compared with Mercury, Ceres is a mere fragment.

In two years from the discovery of Ceres, another small planet was discovered, at nearly the same distance ; and very soon after a third and a fourth. The names of the three are Pallas, Juno, Vesta. There were thus four planets in the place where one should have been. No farther discovery was made till 1845, when a fifth was discovered. This was followed by a sixth in 1847, and, since then, the number has been continually growing. On the 25th of February of the present year (1876) was discovered the 160th.

They are all comparatively small in size. They are invisible to the naked eye ; Vesta alone might be seen as a star of the sixth magnitude to a person that knows where to look for it.

Their orbits, while occupying the position of the supposed planet between Mars and Jupiter, are, as a rule, more eccentric, and more inclined to the ecliptic than the other planets. The first supposition respecting them was that they were fragments of an exploded planet; but, not to mention that the explosion of a planet is unlikely, if they had arisen in that way, their orbits would have all passed through one point, which is not the case. Except their small size, nothing is known of their physical structure; their light is too faint for analysis by the spectroscope.

1061. *Jupiter.*—The giant of the planets. A man there would weigh nearly three times as heavy as on the earth. Eleven times the earth in diameter, it is thirteen hundred times the earth's volume, and three hundred times its mass. It is nearly five times as far from the sun as the earth is; whence the amount of light and heat received from the sun is very small. Yet it is a brilliant planet, notwithstanding.

The surface of Jupiter is crossed by a number of dark belts, which are constantly changing; but are nearly parallel to one another. There are also numerous spots of a more permanent character, although not known to be absolutely fixed. From these is deduced the enormously quick rotation of the planet about its axis; being only ten hours to a complete revolution. Accompanied with this rapidity of rotation, is the obvious flattening at the poles.

The belts are believed to be clouds in Jupiter's atmosphere. But the circumstances of the planet, in respect of the little influence of the sun, and of the greater force of gravity at the surface (nearly three times the earth's), greatly alter the atmospheric conditions. Putting all things together, Mr. Proctor supposes that the planet possesses a great internal heat, and, in this respect, has a greater resemblance to the sun than to the earth. It is subject to changes of colour, of which we do not know the cause.

Jupiter has four moons, or satellites, revolving round him at different distances, and observing all the laws of the planetary motions. Their periods of revolution are small: varying from two to sixteen days. Their orbits are so near the plane of Jupiter's orbit that they frequently pass his body either before or behind. Their passage in front is named a transit; when they pass behind they are eclipsed. Sometimes in passing on the far side they get into Jupiter's shadow without being behind his body: they are then *occulted.*

1062. *Saturn.*—Another huge planet, but less than Jupiter: the *ring* planet. His distance from the sun is nearly ten times the earth's; to him, therefore, the sun's heat and light are almost as nothing. The planet has belts and spots like Jupiter, and from these he is shown also to have a rapid whirl: the period of rotation is ten and a half hours. The density is about one-half of Jupiter's, little more than one-seventh of the earth's.

Saturn, like Jupiter, has a decided atmosphere; which cannot be maintained in the gaseous form by solar heat. By reasoning similar to that applied to Jupiter, he is considered by Mr. Proctor to possess a high degree of heat in his own body.

The ring of Saturn surrounds the planet, at a distance of 9760 miles. Its entire breadth is 37,570 miles, and its thickness about 138 miles. It is not one continuous ring, but a series of rings one within the other. At first was noticed one marked division into two rings, but other divisions have since been made out: an inside dusky and half-transparent ring being apparent. The rings revolve about the body of the planet in ten and a half hours. They are not coherent rigid masses, but streams of meteoric matter, or small satellites, probably mixed with vapour, which is the only constitution that would, under the laws of motion, possess stability.

Saturn has eight satellites, exterior to the ring. The outermost of the eight is nearly four millions of miles distant from the planet, and is almost as large as the moon.

1063. *Uranus.*—The distance of this planet from the sun is nineteen times the earth's distance: the sun's influence being diminished to nearly the four hundredth part of his influence on the earth: so that as far as heat goes the planet would be just as well without the sun; although he would still appear a body of considerable luminosity. The diameter of the planet is four times the earth's; the density one-fifth of the earth's, or little more than the density of water. It has an atmosphere of marked character, and in all probability has a considerable heat of its own.

The planet has four satellites, whose motions are very exceptional. Not only are the orbits very much inclined (nearly at right angles to the ecliptic), but they move in a direction opposed to all the other bodies of the solar system.

1064. *Neptune.*—Remarkable for the history of his discovery. Some unaccounted-for disturbances of Uranus led to the suspicion that there might be an exterior planet yet undiscovered. The place of the planet was computed from the direction of the disturbances, and by means of this cue, the planet was actually detected on the 23rd September, 1846, within a very short distance of the computed place. His distance from the sun is enormous, thirty times the earth's: his period of revolution being a hundred and ten days over 165 years. He is somewhat larger than Uranus, but slightly less dense. One satellite has been discovered.

People often speculate as to whether the other planets are inhabited. The only two that would, from their temperature, permit the existence of living beings such as belong to this earth, are Venus and Mars. The poles of the one planet and the equator of the other might support vegetable and animal life of the terrestrial types.

Comets.

1065. The word "comet" expresses the hairy, bearded, or brush-like appearance of the bodies so named. They must be seen to be conceived. Rare and capricious in their recurrence, their aspect is not only exceptional, but subject to great mutation during the time of their stay. Many of them can be distinguished into a head and a tail, the head being a rounded end, often with a bright point or nucleus, from which proceeds a vast brush or tail of thin luminous matter. So open is the texture, that the stars can be seen through every part, not excepting the head or nucleus. It is in the tailed form that they have awakened the greatest attention and surprise; but many show nothing but a nebulous disc, with a nucleus. On first appearing they are usually faint, but after a time become much lighter—an effect connected with their approach to the sun.

Since their motions have been studied and understood, they are seen to follow the laws of the planetary revolutions, but with considerable differences as to the shape and position of their orbits. These orbits are either very eccentric ellipses, or they are open curves, in which case a comet never revisits the glimpses of the sun. The inclination of the orbits is very various; and the motions often (like the satellites of Uranus) retrograde.

The greatest interest attaches to those that return within moderate periods. The one named *Halley's* has a period of seventy-six years. It was observed by him in 1682, and its orbit calculated. It has returned twice since, according to prediction—namely, in 1759 and 1835; and it has been traced backwards, and identified with a series of recorded comets.

An interesting comet of a short period named after the astronomer *Encke*, who discovered it, revolves in three years and four months, at a mean distance from the sun of little more than twice the earth's. This comet has undergone retardation, which, not being fully accounted for by the perturbing influence of the large planets, has been supposed to give evidence of a thin resisting medium, or ether, in the inter-planetary spaces.

1066. The constitution of the comets is still very obscure. The latest suggestion is that they are vast showers of small bodies of the kind named meteoric stones—a suggestion founded on some remarkable coincidences of comets with meteoric showers, or shooting stars. On this supposition Professor Tait shows what would be the consequence of the encounter of a comet with the earth, which is often spoken of as a possible casualty. We often pass through the tails of comets, if the present doctrine be correct, and the effect is a display of shooting stars like the November meteors. But if we were to pass through the nucleus or head, which is the densest part of a comet in a parabolic orbit, we might be so furiously bombarded with aërolite boulders that "there would be a wholesale massacre of living beings, and destruction of buildings and cultivated land over half the globe." But the probability of the occurrence is excessively small.

The source of light of the comets is still very mysterious. It is not wholly dependent on the solar light, and yet it is not wholly independent, for it increases as the comet approaches the sun.

Meteors and Aërolites.

1067. Among the most familiar appearances at night are the shooting stars, falling stars, or meteors. Often they disappear and leave no trace, but in some instances they are followed by the fall of solid material to the earth. This may be a mere dust shower, or it may consist of solid masses of great variety of sizes, called aërolites. A fine collection of them may be seen in the British Museum. Many are massive blocks weighing several hundredweights. The largest on record is one in Brazil, estimated at fourteen thousand pounds weight.

In composition the aërolites are for the most part largely made up of iron, with small quantities of other metals, especially nickel and cobalt, with copper, tin, manganese, chrome, and molybdenum. They also contain oxygen and carbon, and by means of Sprengel's vacuum Graham succeeded in extracting from them a quantity of hydrogen gas. The material constituents are therefore only those that we find in the earth, but in the form and manner of combination they differ from any terrestrial substance. They are usually covered with a thin black crust, and are very hot when they fall.

The *periodicity* of the meteoric swarms has been established in several instances. The most remarkable epochs of their appearance are from 12th to the 14th of November, and on the 10th of August.

The average height of shooting stars has been estimated at sixty miles. This would be about the beginning of our atmosphere; and the friction of the air might be the cause of their blazing up.

That small masses or blocks of solid matter fly through space in countless millions is a sure inference from the facts. That these masses are gathered into vast swarms, groups, or streams is the probable interpretation of their periodic appearance; not, however, to the exclusion of smaller groups or isolated individuals. The connection of these swarms with comets has been noticed in the previous section.

SECTION VI.

The sun himself is the nearest to this earth of innumerable self-luminous bodies, existing through illimitable space, which, owing to their distance, appear to our sight very small. These are the STARS.

1068. The bodies apart from our solar system are commonly spoken of as the *stars* or the *fixed stars*, because they appear to us to keep their places with relation to one another, and do not shift or wander like the planets, satellites, and comets.

The fixed stars are the bright points of the nocturnal sky. They are of different degrees of brightness, and from that circumstance are classified into stars of the first, second, and other magnitudes. The smallest of those visible to the naked eye are of the sixth magnitude. The number of the visible stars is about two thousand for one half of the heavens, or four thousand for the entire sphere. The stars not seen by the naked eye and discovered by the telescope are vastly numerous; they are classified down to the seventeenth magnitude.

From very early times the stars have been grouped into figures or forms called *constellations*. They are named after men, animals, and fanciful objects. Twelve such surround the heavens in the neighbourhood of the ecliptic, and are called the twelve signs of the Zodiac: *Aries* (the ram), *Taurus* (the bull), *Gemini* (the twins), &c. North of the Zodiac are enumerated twenty-one constellations. Perhaps the most notable is *Ursa Major*, the Great Bear, in which are the seven conspicuous stars named the *Plough*. South of the Zodiac are fifteen constellations, many of which never appear to us: one, named *Orion*, is apparent at a certain season of the year.

Individual stars are designated, according to their relative brightness, by Greek letters and by numbers, under their several constellations, as α, β, γ, *Ursa Majoris*; 61 *Cygni* (the Swan).

1069. To know the real sizes of the starry bodies, the first thing is to find their *distances*. The ordinary methods of finding distance by parallax were for a long time unavailing. For although the diameter of the earth's orbit, 183 millions of miles, was taken as the base line, no sensible parallax could be observed. Now, a parallax of 1″, or the displacement of a star by that quantity, when viewed from opposite positions of the earth in her orbit (that is, at a six months' interval), corresponds to a distance of 19 billions of miles, or more than two hundred thousand times the distance of the sun. Such a parallax is within the means of observation, although it is doubtful whether smaller amounts can be relied on. The first star believed to have an annual parallax was 61 *Cygni*, estimated by Bessel at about a third of a second. Next was one of the brightest of the southern stars, α *Centauri*, whose parallax was estimated by Henderson at very nearly a second; the latest estimate being 0″·91, or about nine-tenths of a second. The corresponding distance would be 21 billions of miles. For the quickest movement in nature, the movement of light, to traverse this distance would take three and a half years.

If this be one of the nearest stars, we may judge what are the distances of the others. It is not certain that greater brightness means greater nearness; "one star may differ from another in glory," or in size and light-giving power.

The star α *Centauri* is three times as bright as our sun would be at the same distance.

1070. A singular fact concerning the stars is, that in regard to brilliancy, some of them are variable, hence called the *variable stars*. They go through periods of increase and diminution. Two or three hundred of such have been noticed. The cause may be either the intervention of a dark body, or the unequal manifestation of the light and dark parts of the surface, corresponding to our solar spots. Also there are instances of stars coming into view for a time, and then vanishing.

While in the multitude of the stars there must be every degree of proximate or apparent position, cases have been discovered of couples changing their relative position as if by a proper motion, on the part of one or both. These are the *Double Stars*, first discovered by the elder Herschel. Periods of revolution have been assigned in some instances. The double star 70 *Ophiuchi* accomplishes a revolution in about 80 years. Sir W. Herschel observed 2400 double stars. There are groups of more than two, called *Multiple Stars*. There are now known upwards of 6000 double and multiple stars. In them we have an extension of our ideas of the grandeur of the universe. Besides systems made up of a central sun with its attendant planets, we are presented with two or more suns revolving in the same system, by which their planets might enjoy an almost perpetual day.

1071. The farther discovery has been made that the stars are not absolutely fixed, but have in many instances a *proper motion* in space. No doubt this motion is very slow, otherwise it would lead to displacements that would have been discoverable long since. The question is naturally suggested: Is our sun fixed in space? As the effect of his moving would be to open up the stars that he approached towards, and make closer those that he receded from, there is a means of determining the fact. It is actually shown that he is steadily advancing towards a certain point in the heavens located in the northern constellation *Hercules*.

The spectroscope employed upon the stars has shown that they do not essentially differ in constitution from the sun. As in the sun, hydrogen is a prevailing element. Other substances identified are sodium, magnesium, calcium, iron, bismuth, antimony, mercury, tellurium.

While many of the stars are of a brilliant white colour, there are great varieties of colour among the rest. There are numerous shades of red, yellow, and blue, which would seem to show great differences in their constituent materials. The spectroscopic observations also show the same variation in the predominating elements.

1072. *Nebulæ.*—In various parts of the heavens are discerned cloudy or hazy patches, which have given rise to much study Many of these patches, when examined by powerful telescopes, have appeared to be clusters of stars, while others have preserved their nebulous aspect. It was not unreasonable to suppose that these last also, under still more powerful telescopes, might appear to be nothing but dense masses of stars. But there are now grounds for thinking that there are irresolvable nebulæ, or collections of diffused hazy light, indicating a peculiar celestial phenomenon, explained as uncondensed stars. Observed by the spectroscope, these nebulæ are seen to contain glowing hydrogen gas.

The star clusters are suggestive of many reflections as to the constitution of the material universe. They would seem to indicate the existence of detached star-systems, or galaxies, self-contained, and possessing innumerable suns (each perhaps with planets) performing movements among themselves under gravitation. It is conjectured that our sun is a member of the huge galaxy, appearing as the *milky way* (a flattened form, with a cleft in the edge), which contains the great mass of the visible stars. The nebulæ (star clusters) occur in all parts of the heavens, and represent other galaxies like our milky way, strewn in the immeasurable depths of space.

PART VI.

ANIMAL PHYSICS.

SECTION I.—ANIMAL MECHANICS.

ANALYSIS OF THE SECTION.

Animal Mechanics.—Proportion of solids and liquids in the human body.—The large proportion of water in the structures of the body.—The properties of the organs dependent on water.—Relative weight of mineral and organic matter in the body. The mechanism of the skeleton.—The skull.—Ossification.—Structure of the teeth.—Serpent's tooth.—The spine or back-bone.—Its form, flexibility, and strength.—The ribs and their muscles.—The shoulder joint.—The bones of the arm.—Use of ligaments.—The hip-joint.—Thigh-bone.—The knee-joint and legs.—The arch of the foot.—Effects of artificial pressure. Muscular force.—Its exhaustion. Composition of bone.

Animal Mechanics—Mechanism of the Human Skeleton.

1073. HAVING in a former part of the volume reviewed the doctrines of general mechanics, we can proceed, with the light thence derived, to consider the solid framework of the human body, a perfect structure which Divine Wisdom has willed into existence to serve the purposes of life and happiness to man.

There is scarcely a part of the animal body, or an action which it performs, or an accident that can befall it, or a piece of professional assistance which can be given to it, that has not a close relation to the truths of natural philosophy as here set forth. Three centuries have not yet passed since the renowned Dr. Harvey made the most important discovery in regard to the nature of living beings which anywhere had yet been made, namely, that of the never-ceasing circulation of the blood in every part of the animal frame.

1074. The human body is composed of solids and liquids, the former represented by the bones, the flesh, and soft organs; the latter chiefly by the blood. We should form a very inadequate notion of its constitution, if we restricted the liquid portion to the blood, the average amount of which, in the adult body, is estimated at thirty pounds. At least two-thirds of the weight of the human body are represented by water. Water is present even in the bones; but if we except these, three-fifths of the flesh and solid organs, and about four-fifths of the liquid constituents, consist of water. The flexibility, softness, elasticity, tenacity, and other physical properties of the soft organs and muscles, are due to the presence of water. A dry muscle could not contract; and ordinary skin, which is highly flexible and elastic, loses these physical properties and becomes hard, dry, and brittle, when deprived of water. Without this abundance of water in the organs, the living powers of the body could not be exercised. These remarks equally apply to the whole animal kingdom. An oyster contains 81 per cent. of water, and there are some small jelly-fish (*acalephæ*) which contain as much as 99 per cent. of this liquid, so that they might be almost described as living water. From calculations based on the chemical analysis of bone and of the solid and fluid constituents of the body of an adult, weighing 150 pounds, it appears that 100 pounds consist entirely of water, and the residuary weight is thus made up,—of dry organic matter, 34 pounds; earthy or mineral matter, chiefly phosphate and carbonate of lime and common salt, mixed with small quantities of earthy and other salts, and oxide of iron, 9 pounds; and of oil or fat, 7 pounds. It is probable that the proportion of water is even greater than that which is here assigned; as it is, it amounts in an adult to ten gallons!

1075. In reference to the skeleton, the *cranium* or *skull* has been already mentioned as an instance of the arched form answering the purpose of giving strength. The brain, in its nature, is so delicate or susceptible of injury, that slight local pressure disturbs its action. Hence a solid covering like the skull was required, with those parts of it made stronger and thicker which are most exposed to injury. An architectural dome is constructed to resist one kind of force only, always acting in one direction, namely gravity, and therefore its strength increases regularly towards the bottom, where the weight and horizontal thrust of the whole are to be resisted; but in the skull, as in a barrel or egg-shell, the mere tenacity of the substance is many times greater than that which is sufficient to resist gravity, and therefore its peculiar form is calculated to resist forces of other kinds, operating in all directions. When we reflect on the strength displayed by the arched film of an egg-shell, we need not wonder at the severity of pressure, and even of blows, which the cranium can withstand.

In the early fœtal state, that which afterwards becomes the strong bony case of the brain, exists only as a tough flexible membrane. Ossification commences in this membrane long before birth, at a certain number of points from which it spreads, and the portions of the skull formed around these points, soon acquire the appearance of so many scales or shells applied on the surface of the brain, and held together by the remaining membrane not yet ossified. These afterwards become firmly fixed together, by projections of bone from the edges of each, shooting in among similar projections of the adjoining ones, until all mutually cohere by perfect dovetailed joints, as does the work of a carpenter. These joints are called the sutures of the cranium, and are visible to extreme old age. Through early childhood, the cranium remains to a certain degree yielding and elastic, causing the falls and blows, so frequent during the lessons of walking, to be borne with comparative impunity.

A severe blow on a narrow part of the skull, as the blow of a hammer, generally fractures and depresses the part struck; while one less severe, but with more extended contact, being stoutly resisted by the arched form, often injures the skull by what corresponds to the *horizontal thrust* in a bridge, causing a crack at a distance from the place struck, generally half-way round to the opposite side. This kind of fracture is well known to medical men under the name of *counter-stroke*. Thus it often happens that a violent blow on the summit of the head causes a fatal fracture through the base of the skull.

1076. *In the lower jaw* we have to remark the greater mechanical advantage, or lever-power, with which the muscles act, than in other parts of animals. The temporal muscles pull almost *directly* across, or at right angles to the line of the jaw, while in most other cases, as in that of the muscles about the shoulder-joint lifting the arm, the muscles act very *obliquely*, and with power diminished in proportion to the obliquity. Even the human jaw can crush a very resisting body; and the jaws of the lion, tiger, shark, or crocodile, have an astonishing power of crushing substances.

The *teeth* rank high among those parts of the animal body which appear almost as if they were the results of distinct miraculous agencies constantly renewed, so difficult is it to suppose simple laws of life capable of producing the variety of form and fitness, constantly changing with age, which they exhibit. They constitute a beautiful set of chisels and wedges, so arranged as to be most efficient for cutting, tearing, and grinding the food, with an exterior enamel so hard that few substances in nature can make any impression upon it. In the *Rodentia*, or gnawing animals, such as the beaver, rat, and squirrel, the front of the tooth is formed of a layer of hard enamel, while the back part consists of dentine or osseous matter. As this is worn away more rapidly by friction than the enamel, the edge of the tooth is always kept sharp. In early states of human society, teeth were used for many purposes for which steel is used now. It seems, however, as if the laws of life, marvellous to human intellect as they are, had still been inadequate to cause teeth, cased in their hard polished enamel, to expand or grow as the softer bones grow ; and hence has arisen a provision more extraordinary still. A set of small teeth come soon after birth, and serve the child until six or seven years of age : these then fall out, and are replaced by larger ones, which endure for life ; the number of the latter being completed only when the man or woman is full grown by the four teeth, called wisdom teeth, then appearing to fill up the more spacious jaw.

Nothing can be firmer than the setting of the fangs of the teeth in the bony cavities of the jaw. It resembles that of a nail driven into a board, and is known under the name of *gomphosis* (γόμφος, a nail). The teeth have to sustain great force during mastication, and by this mode of immovable attachment the pressure is equalized.

The teeth of all animals are admirably adapted by form and structure for their intended uses. The poison teeth or fangs of the rattle-snake and other venomous serpents are in this respect remarkable. The tooth is curved (see fig. 324), and is grooved or channelled on the front or convex side, as if it were folded upon itself. It is through this channel that the poison is ejected into the deep and curved puncture, made by the bite through the skin. The point of the tooth is solid, intensely hard, and finely sharpened. It consists of pure enamel. The channel or groove through which the poison is discharged terminates in the front of the tooth at a short distance above the point (*a*, fig. 324). By this arrangement its sharpness is preserved. The

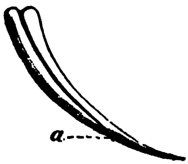

Fig. 324.

base of the tooth is on a movable joint, so that it lies back in the upper jaw until the animal uses it, when the act of bringing it forward, jerks the poison through it. There are several rudimentary fangs ready to supply the place of this, if broken.

The spine or backbone, in its structure, has as much of beautiful mechanism as any part of our complex frame.* It is the central pillar of support and great connecting medium of the other parts. It has, at the same time, the office of containing within itself, and of protecting from external injury, a prolongation of the brain, called the spinal marrow, more important to mere animal life, than the greater part of the brain itself. It thus unites in itself the apparent incompatibilities of great elasticity, great flexibility in all directions, and great strength, both to support a load and to defend its important contents.

1077. The head rests on the elastic column of the spine as softly as the body of a carriage rests upon its springs. Between each two of the twenty-four vertebræ, or distinct bones of which the spine consists, there is a soft elastic *intervertebral substance*, about half as bulky as a vertebra, and which yields readily to any sudden jar. Then the spine has a waved or bent form somewhat like an italic *ſ*, as is perceived on viewing it sideways, or in profile, and owing to this, also, it yields to any sudden pressure operating against either end. The bending might seem a defect in a column intended to support weight; but the disposition of the muscles around, is such as to leave all the elasticity of that form, and a roomy thorax or chest, without any diminution of strength. It comes forward in the neck to support the skull: it recedes in the chest to allow space for the lungs, and it again advances to support the viscera of the abdomen.

The spine has been compared to a chain, because it consists of twenty-four distinct pieces or bones. They are kept in contact by smooth rubbing surfaces, which allow of a degree of motion in all directions; and a little motion comparatively between two adjoining pieces, becomes a great extent of motion in the whole line of vertebræ. The *strength* of the spine as a whole, is shown in the fact that a man can carry upon his head or back a weight heavier than himself; and the strength of each separate vertebra surrounding the spinal marrow is evident in its being a double arch, or strong irregular ring. The spine increases in size towards the bottom, in just proportion, as it has more weight to bear. The articulating surfaces of the spine are so numerous, and so exactly fitted to each other, and are connected by such a number of ligaments of great strength, that the combination of pieces becomes, in reference to motion, a much stronger column than a single bone of the same size would be. It is also remarked that in accidents affecting the spine, the bones are more readily fractured than displaced.

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* The presence or absence of a spine creates two great divisions of the animal kingdom: 1, the *Vertebrata*, including man and the higher classes of animals, which are endowed with this structure, and with it a brain and spinal marrow; and, 2, the *Invertebrata*, which are destitute of a spine.

Considering the great number of parts forming the spine, and their nice mutual adaptation, it might be expected that injuries and diseases of the structure would be very frequent. The reverse, however, under natural circumstances, is true; and while many books have been published on the diseases of almost every other part of the body, few comparatively have appeared on spine affections, and these have been chiefly of recent date. One reason of this is that fashions unfavourable to female health began to prevail about the end of the last century, particularly the practice of compressing the chest and abdomen by what was called *tight-lacing*, and a considerable proportion of the young ladies, grew to womanhood with weakened and crooked spines.

1078. *The ribs.*—Attached to twelve vertebræ in the middle of the back there are the ribs, or bony stretchers of the cavity of the chest, constituting a structure which solves, in the most perfect manner, the difficult mechanical problem of making a cavity with a solid exterior, which shall yet be capable of dilating and contracting itself. Each pair of corresponding ribs may be considered as constituting a hoop, which hangs obliquely down from the place of attachment behind, and so that when the forepart of all the hoops is lifted by the muscles, the cavity of the chest is enlarged. So great is this obliquity, that a straight line, touching the upper edge of the sixth rib behind, would be on a level with the upper edge of the third rib in front.

We have to remark the double connection of the rib behind, first, to the bodies of two adjoining vertebræ, and then to a process or projection from the lower, thus effecting a very steady joint, and yet leaving the necessary freedom of motion; and we observe the fore part of the rib to be joined to the breast-bone by a flexible and elastic cartilage, which allows the degree of motion required there, without the complexity of a joint, and by its elasticity admirably guards against the effects of sudden blows or shocks.

The muscles which have their origin on the ribs and their insertion into the bones of the arm, afford us an example worth remembering of action and reaction being equal and contrary. When the ribs are fixed, these muscles move the arm; and when the arm is fixed, as by resting on a chair or other object, they with equal force move the ribs. The latter occurrence is seen in the efforts made to breathe during the fits of asthma.

1079. *The shoulder-joint* is remarkable for combining a great range and variety of motion with considerable strength. The large round head of the shoulder-bone, in order that it may turn freely in all ways, rests upon a shallow cavity or socket of the shoulder-blade; and the danger of dislocation from this shallowness of the socket, is guarded against by two strong bony projections from the shoulder-blade above and behind. In order to increase the range of motion to the greatest possible degree, the bone called the shoulder-blade, which carries the socket of the arm, can itself slide about upon the convex exterior of the chest, having its motion limited, however, in certain directions by its connection, through the collar-bone or clavicle, with the sternum or bone of the breast.

The scapula, or blade-bone, just spoken of, is remarkable as an illustration of the mechanical rules for combining lightness with strength. It has the strength of the arch from being a little concave, like the "dished wheel" described in Art. 276, p. 154, and its substance is chiefly collected in its borders and spines, with thin plates between, as the strength of a wheel is collected in its rim, spokes, and nave.

The bones of the arms, considered as levers, have the muscles which move them attached very near to the fulcra, and very obliquely, so that these muscles, from working through a short distance, compared with the displacement of the resistances at the extremities, require to be of great strength. It has been calculated that the muscles of the shoulder-joint, in the exertion of supporting a great weight upon the hand, pull with a force of more than a thousand pounds.

Notwithstanding all the securities to the shoulder-joint now described, in the infinite variety of twists, and falls, and accidents to which men in the busy scenes of life are liable, the joint is frequently dislocated; that is, the rounded head of the humerus or arm-bone slips from its socket, with instant loss of power as a consequence.

1080. *The os humeri,* or bone of the upper arm, is not perfectly cylindrical, but like most of the other bones called cylindrical, it has ridges to give strength, on the principle explained in the remarks "on strength of materials." (Art. 287.) These ridges also answer another important purpose. They serve to give a firmer attachment of the muscles to bone. They are most strongly marked in the bones of carnivorous animals.

The elbow-joint is a correct hinge, and so strongly secured that it is rarely dislocated without fracture.

The fore-arm consists of two bones, with a strong membrane between them, binding them together. Its great breadth from this structure affords abundant space for the origin of the many muscles which go to move the hand and fingers : and the very peculiar mode of connection of the two bones gives to man that most useful faculty of turning the hand into what are called the positions of pronation and supination,—exemplified in the action of twisting, or of turning a key in a lock.

The wrist.—The eight small bones with their numerous joints, forming the wrist, have a signal effect in deadening, in regard to the parts above, the shocks or blows which the hand receives, the force being thus distributed over a much larger surface.

The annular ligament is a strong band surrounding the joint, and keeping all the tendons, which pass from the muscles above to the fingers, close to the joint. It answers the purpose of so many fixed pulleys for directing the tendons; without it they would all, on action, start out like bow-strings, producing deformity and weakness.

1081. *The pelvis*, or strong irregular ring of bone on the upper part of which the spine rests, and from the sides of which the legs descend, forms the central mass of the skeleton. A breadth of bone was wanted here in order to connect the single column of the spine with the lateral columns of the legs, and a circle was the lightest and strongest. If we attempt still farther to conceive how a circle might be modified so as to fit it—for the spine to rest on, for the heads of the thigh-bones to roll in, for muscles to spring from, both above and below, and for the person to be able to sit upon, we shall find that all such anticipations of what was desirable and necessary in a human being, are realized in the most complete manner.

The hip-joint exhibits the perfection of the ball-and-socket articulation. It allows the leg to turn on its axis and to move the foot round in a circle, as well as to have the great range of backward and forward motion, exhibited in the action of walking. When we see the elastic, tough, smooth cartilage which lines the deep socket of this joint, and the similar glistening covering of the ball or head of the thigh-bone, and the lubricating synovia, or joint-oil, poured into the cavity by appropriate secretories, and the strong ligaments giving strength to all around, we feel how far the most perfect of human works falls short of the mechanism exhibited in nature.

The femur, or *thigh-bone*, is remarkable for its two projections near the top, called trochanters,* to which the chief muscles are attached, and which lengthen considerably the levers by which the muscles act. The shaft of the bone is not straight, but has a considerable forward curvature. It might be supposed that this was a structural defect, the bone being a pillar to support a weight; but the bend gives it in reality the strength of the arch, to bear the action of the four large muscles called *vasti*, which make up the bulk of the thigh.

The knee is a hinge-joint of complicated structure, claiming the most attentive study of the surgeon. The rubbing parts, or those in contact which receive and convey the weight of the body, are flat and shallow, and therefore the joint has little strength from its form; but it derives security from the numerous and singularly strong ligaments which surround it. The ligaments on the inside of the knees resemble, in two points, the annular ligaments of joints, *viz.*, in having a constant and great strain to bear, and yet in becoming stronger always as the strain increases.

In the knee there is a singular provision of loose cartilages between the ends of the bones. They have been called friction-cartilages, from a supposed relation in use to friction wheels; but their real effect seems to be, to accommodate, in the different positions of the joint, the surfaces of the rubbing bones to each other.

Under the head of *Pneumatics*, it has been explained that the bones forming the joints are held everywhere in smooth contact, independently of their ligaments, by a constant soft pressure of the atmosphere, amounting in the knee, for instance, to upwards of sixty pounds. (Art. 424.)

1082. The great muscles on the fore part of the thigh are contracted into a single tendon a little above the knee, over and in front of which that tendon has to pass to reach the top of the leg, to which it is attached. The part of the tendon in front of the joint becomes solid or bone, and forms the patella or knee-pan, often called the pulley of the knee. This peculiarity enables the muscles to act more advantageously, by increasing the distance of the rope from the centre of motion. The patella is, moreover, a sort of shield or protection to the fore-part of this important joint.

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* From τροχάω, I turn.

The leg below the knee, like the fore-arm already described, has two bones. These, by their ridges and surfaces, present a large space for the origin of the numerous muscles required for the movements of the feet and toes, and they form a compound pillar of greater strength than the same quantity of bone as one shaft would have had. The individual bones also are angular instead of round, hence deriving greater power to resist blows, and giving a more perfect attachment to the powerful muscles of the leg.

The ankle-joint is a perfect hinge of great strength. There is in front of it an annular ligament, by which the greater part of the tendons passing downwards to the foot and toes are kept in their proper places. One of these tendons passes behind and under the bony projection of the inner ankle, in a smooth appropriate groove, exactly as if a little fixed pulley had been placed there.

The heel, by projecting so far backwards, is a lever for those strong muscles to act by, which form the calf of the leg and terminate in the tendo-Achillis. The muscles, by raising this tendon, lift the body, in the actions of standing on the toes, walking, and dancing.

1083. In a graceful human step, the heel is raised a little before the foot is lifted from the ground, as if the foot were part of a wheel rolling forward; and the weight of the body, thus supported by the muscles of the calf of the leg, as just described, rests for the time on the forepart or ball of the foot and the toes. There is at this time a considerable bending of the foot. But where strong wooden shoes are used, or any shoe with a sole so stiff that it will not yield and allow this bending, the heel is not raised at all until the whole foot rises with it, so that the muscles of the calf are scarcely used, and in consequence they soon dwindle remarkably in size. Many of the English farm-servants wear heavy stiff shoes, and in the London markets they may be seen as the drivers of country waggons, with fine robust body and arms, but with legs which are almost spindles, producing an awkward and unmanly gait. The brothers of these men, otherwise employed, are not so mis-shapen; and even they themselves, when they chance to become soldiers, and are trained in military exercises, lose their peculiarity. An example of an opposite kind was formerly seen in Paris, where, as the streets had no side pavements, and the ladies consequently had to walk almost constantly on tiptoe, over round stones, the great action of the muscles of the calf gave a conformation of the leg and foot, to match which the Parisian belles proudly challenged all the world,—not aware, probably, that it was a defect of their city to which the peculiarity was due.

Fashion has lately succeeded to some extent in reversing these natural results of healthy muscular action. It has been pointed out by Sir James Paget that the modern practice of attaching high heels to boots and shoes, destroys the proper action of the muscles of the calf of the leg by shortening and relaxing the point of attachment to the heel, and throwing the weight of the body more upon the instep than nature intended. This becomes a source of weakness and deformity, and it causes a person to walk with a tottering and unsteady gait. European ladies, while condemning the Chinese for their unnatural treatment of the human foot, are themselves guilty of cultivating deformity in another fashion.

That men lose not a little of the strength and command of their lower limbs by being condemned to use too small or too rigid shoes cannot be doubted; and the fact is of no small importance to a military people, for the result in battle of a charge where bayonets clash, must depend almost as much on the strength of the legs as of the arms.

A person confined to bed for a week or two by illness has generally to remark a much greater wasting of the legs than of the arms; the reason of which is, that the muscles of the leg being more in use than those of the arms, their ordinary bulk is more dependent on use, and they suffer a corresponding change from inaction.

The heel-bone of the negro race is longer, and projects more behind than that of the European; hence, it does not require so powerful a muscular effort to raise it. The muscles of the calf of the leg are therefore, *cæteris paribus*, less developed in them than in our own race.

1084. *The arch of the foot* may be noticed as another of the many provisions for saving the body from shocks by the elasticity of the supports. The heel and the ball of the toes are the two extremes of the elastic arch, and the leg rests between them.

This explains why the measure of a person's foot taken when seated is considerably less both in length and breadth than when the person stands, with the whole weight of the body acting to expand or lengthen the foot. It also helps to explain why boots and shoes are often made too small. But it is a whim of unreasoning fashion which holds that the human foot, as given by nature, is improperly large, and requires to have its growth controlled by the use of tight shoes. Persons who act on this notion, often have painful corns or bunions on their feet, and distorted toes, as the usual effects of pressure or friction, so that the act of walking is highly painful. Over the vast empire of China this absurdity is carried to an extent which is monstrous. Tight bandages are kept on the feet of the children from an early age, and the females of the higher classes become truly cripples for life. The foot is stunted in growth, and is practically converted into a sort of hoof, the sole of the foot being almost entirely obliterated.

The practice seems to be a sister folly to that of letting the finger-nails grow to a hideous length within cases worn to defend them. Both deformities seem intended to show that the individuals are of a high order, not requiring to use either feet or hands to gain a livelihood.

Connected with elasticity, it is interesting to remark how imperfectly a rigid wooden leg answers the purpose of a natural leg. The centre of the body, when supported by the wooden leg, which remains always of the same length, must describe, at each step, an exact portion of a circle, of which the bottom knob of the leg is the centre ; and the body is therefore constantly rising and falling somewhat like an animal advancing by leaps ; but with the natural legs, which, by gentle flexure at the joints, are made shorter or longer at different parts of the step as required, the body is carried along softly in a manner nearly level. In like manner, a man riding on horseback, if he keep his back upright and stiff, has his head jolted by every step of the trotting animal ; but the experienced horseman, even without rising in the stirrups, by letting his back yield a little at every movement, as a bent spring yields during the motion of a carriage, can carry his head smoothly along.

1085. The muscular force of man has been used as a working power in various ways, as in lifting and carrying a weight, pulling at a rope, turning a winch, or walking in the inside of a large wheel to move it, as a squirrel moves his little wheel, or in undergoing the punishment of the treadmill, which is utilized in prisons for a variety of purposes. Each of these has some peculiar advantage ; but the mode in which, for the purpose of lifting weights, the greatest effect may be produced, is for the man to carry up to a height his body only, and then to let it raise a load equal to itself by its weight in descending. A bricklayer's labourer would be less fatigued, while lifting bricks to the top of a house by ascending the ladder without a load and then raising bricks of nearly his own weight over a pulley each time in descending, than by carrying fewer bricks and himself up together, and working down again without a load, as is still usually done in accordance with old habit. Reflection, independently of experiment, would naturally anticipate such a result, for the load which a man should be best able to carry, is surely that from which he can never free himself,—the load of his own body. Accordingly the strength of muscles and disposition of parts are all such as to make his body appear light to him.

Animal power being exhausted in proportion as well to the time during which it is acting as to the intensity of force exerted, there may often be a great saving of power by doing work quickly, although with a little more exertion during the time. Suppose two men of equal weight to ascend the same stair, one of whom takes only a minute to reach the top, and the other takes four minutes, it will cost the first but a little more than a fourth part of the fatigue which it costs the second, because the exhaustion has relation to the *time* during which the muscles are acting. The quick mover must have exerted more force in the first instant, to give his body the greater velocity which was afterwards continued, but the slow mover has supported his load four times as long.

A healthy man will run rapidly up a long stair, and his breathing will scarcely be quickened at the top; but if he walk up very slowly his legs will feel considerable fatigue, and the body will generally sympathize. For the same reason coach-horses are sometimes spared by being made to trot quickly up a short hill, and being then allowed to go more slowly, so as to rest at the top.

The rapid waste of muscular strength which arises from continued action is felt by keeping an arm extended horizontally for some time. Few persons can continue the exertion beyond a minute or two. In animals with heavy projecting necks there is a singular provision of nature in a very strong elastic band attached to the back or upper part of the neck, which nearly supports the head independently of muscular exertion. In the horse this band (called *ligamentum nuchæ*) is of great breadth, and saves great muscular force by supporting the heavy head of the animal.

In further illustration of the truth that strength is saved in many cases by doing work quickly, we may recall the fact explained in Art. 179, that a body thrown or shot upwards with double velocity, rises four times as far as when shot with a single velocity, or half of the other.

This saving of strength is also indicated in the use of the modern bicycle. By the aid of this machine a man has been able to travel from Bath to London, a distance of 112 miles, in nine hours. The large muscles of the thighs, and those which connect the thighs with the trunk, are here chiefly brought into action, while the muscles of the leg are mainly exerted in walking. By the mechanical effect of a wheel of large diameter (56 inches), a great space of ground is traversed in a short time. It would be impossible for a man to go over this distance in the same time, either by walking or running.

1086. *The Skeleton.*—The skeleton in a full-grown adult does not form more than about one-fifteenth part of the weight of the body. A well-formed male skeleton weighs about ten pounds and a half, and a female skeleton nine pounds—the bones being in a dry state. In a general review of the skeleton there are some physical points worthy of remark, 1st, the nice adaptation of all the parts to one another, and to the strains which they have respectively to bear ; as—in the size of the spinal vertebræ gradually increasing from above downwards—the bones of the leg being larger than those of the arm, and so on. 2ndly, the objects of strength and lightness combined ; as by the hollowness of the long bones—their angular form—their thickening and flexures in particular places where great strain has to be borne—the enlargement of the extremities of the bones to which the muscles are attached, lengthening the levers by which these act. 3rdly, the nature and strength of material in different parts, so admirably adapted to the different purposes to be served. The bones are constituted of mineral and organic matter—the proportions of these varying in some respects, but being always adapted to the uses to which the bone is put. In the long bones of the arms and legs, where great strength is required, the mineral matter, consisting chiefly of phosphate and carbonate of lime, forms about two-thirds, and the organic matter (consisting of osseine or gelatine) about one-third of the weight of the bone in a dry state. An undue proportion of the mineral substances renders the bone more liable to fracture from slight causes, while a deficiency of it leads to a softening and yielding of the bone under the weight of the body or muscular action. There is nothing more wonderful in the structure of the skeleton than the mode in which these mineral and organic constituents of bone are distributed. If a bone like the scapula or blade-bone is placed for some time in a diluted acid, the mineral matter is entirely removed, while the organic matter remains. The bone retains its shape and size, but is now perfectly flexible and elastic. On the other hand, if this bone is heated to a very high temperature in an open furnace, it is first blackened from the carbon contained in the animal substance, and it ultimately becomes white and brittle, consisting entirely of mineral matter—*i.e.*, of the phosphate and carbonate of lime. If this experiment is carefully performed, the bone will preserve its form and shape, but it is light and porous. These results show that there is no casual admixture of the mineral and organic constituents of bone, but a uniform and perfect diffusion of the two kinds of matter throughout the whole of the mass. Each molecule of mineral matter is associated with a proper amount of animal matter to cement the whole into a uniform solid.

1087. In the teeth, which are intended for tearing, grinding, and masticating all kinds of matter used as food, a harder material than bone is required. The body of the tooth consists chiefly of a bony substance (*dentine*), but this is covered more or less by *enamel*. They are both much harder than bone—the dentine containing 72, and the enamel 96 per cent. of mineral matter, chiefly phosphate of lime. The *enamel* is the hardest of all the tissues in the body, a property partly due to the very large proportion of mineral matter contained in it, and partly to its physical disposition—*i.e.*, the close and compact manner in which it is deposited on or around the dentine of the tooth. On the upper surface of the tooth of the elephant, the dentine and the enamel are seen arranged in alternate layers traversing the width of the tooth. In the Asiatic elephant the enamel assumes a wavy form, while in the African variety the enamel is deposited in a narrow, lozenge-shaped form. As the dentine wears away more rapidly than the enamel, the surfaces of these large teeth are always in a rough state, and well fitted for grinding the hard food on which the animals live. Passing from the teeth to the bones of the cranium or skull, it may be remarked that, although the bones are thinner, they are tough and resisting.

In the middle of the long bones the bony matter is compact and little bulky, to leave room for the swelling during action of the muscles lying there; while, at each end, with the same quantity of matter, it is large and spongy, to give a broad surface for articulation; and in the spine, the bodies of the vertebræ, which have between each two an elastic bed of intervertebral substance, are light and spongy, while their articulating surfaces and processes are very hard. In the joints we see the tough elastic smooth substances, called cartilage, covering the rubbing ends of the bones, defending and padding them, and destroying friction. In infants we find all the bones soft or cartilaginous, and therefore calculated to bear without fracture, the falls and blows incidental to early age; and we see in certain parts, where elasticity is necessary or useful, the cartilage retains its character for life, as at the anterior extremities of the ribs. About the joints we have to remark the ligaments which bind the bones together, possessing a tenacity scarcely equalled in any other known substance; and we see that the muscular fibres, whose contractions move the bones and thereby the body,—because they would have rendered the limbs clumsy, even to deformity, had they passed unchanged over the joints to the parts which they have to pull,—attach themselves at convenient distances from the joint to a strong cord called a tendon, by means of which, like a hundred sailors at one rope, they make their effort effective at any distance. The tendons are remarkable for the great strength which resides in their slender forms, and for the lubricated smoothness of their surfaces. Many other striking particulars might be enumerated, but these may suffice.

SECTION II.—ANIMAL HYDRAULICS AND PNEUMATICS.

ANALYSIS OF THE SECTION.

1. The Circulation of the Blood.—*There is constantly streaming from the heart to all parts of the animal body a red opaque fluid, the blood, carrying fresh nourishment to the various tissues and organs, and taking from them the results of waste, or old material which has served its purpose in the body, and has to be carried away. The motion is kept up chiefly by the pumping action of the heart, forcing the blood along the tubes called* arteries, *which gradually ramify to every spot, through the extreme branches, called from their minuteness* capillaries, *into a corresponding tubular system called* veins, *which carry it back to the lungs to be purified and renewed.*
2. Respiration or Breathing.—*The chest is a cavity which alternately expands and contracts like a pair of bellows, thereby taking in and again expelling a certain volume of atmospheric air. The air comes nearly into contact with every particle of the circulating blood as this passes at every revolution through the spongy lobes of the lungs which occupy the chest. These lobes consist chiefly of delicate air-cells and minute capillaries, so thin that air can immediately act through their substance. Great changes are produced in the blood by the air, and it is again rendered fit to support life.*

The Circulation of the Blood.

1088. There are few things more remarkable in the history of the progress by which man has arrived at his present knowledge of nature, than that, until within a comparatively recent period, he was ignorant of the fact that the blood in his own and in other animal bodies, is constantly travelling from the heart to all other parts, and back again. This truth was at variance with strong appearances, and the most fixed prejudices. It fell to the lot of our countryman, Dr. Harvey, to make this grand discovery, and he was probably led to it from having a more extensive knowledge of mechanical philosophy than was common among his professional brethren at that time. He published his proofs in the year 1628.[*] A person who tries to imagine what the science of medicine could have been while it took no account of this fact, on which, as a basis, nearly all correct reasoning about the phenomena of life and disease must rest, is prepared for what old medical books exhibit of the writhings of human reason, in attempts to account for numerous facts, or to form theories, while a fatal error was mixed with every supposition. The chief circumstance which prevented the earlier discovery of the circulation was, that, on examining dead bodies, the arteries were always found to be without blood in them, while the veins were charged with it; which was the reason, also, of the first-named vessels being called *arteries* or *air-tubes.*

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[*] Exercitatio de motu cordis et sanguinis.

We now know, that, as water from a central source spreads over a large city in pipes, to supply the inhabitants generally, so in the human body, does the blood spread from one centre, the heart, through the arteries, to nourish all the parts, and to supply to the liver, kidneys, stomach, and other organs, the materials for secretion and excretion. It then returns by the veins to the heart, and thence to the lungs, to be purified and to have its waste so replenished that it may again renew its course through the body.

In the water-works of a great city, the motion is given by a pump-barrel and piston, worked by steam power. In the human body the pump of the blood is the heart, a strong muscular bag, which relaxes to let blood enter through a valve at one side, and then, by contracting, forces it out again through a valve on the other side into the arterial tube, which carries it forward. This kind of action is well illustrated by the common caoutchouc-bag syringe, A, worked by the force of a hand squeezing it. The bag, A, is of the size of an orange. Its entrance-tube, *b*, if immersed in water, admits the charge through the valve at *b*, which then closes to prevent any return. On then squeezing the bag with the hand, the water in it is forced out through the valve, *c*, and jets from the end of the tube, *d*. On ceasing to squeeze, the bag is refilled from *b*, while the valve, *c*, prevents the return of what had already passed through. If an elastic tube, as sketched here by the dotted lines, *d*, *e*, *f*, *b*, be added to form an open communication between the two orifices of outlet and inlet, and if the hand

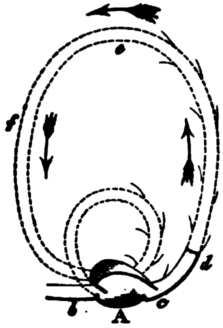

Fig. 3·5.

then contract at intervals like the beats of the heart, a strong current or circulation of the water through the bags and tubes will be produced, like that of blood in the living body,—with this difference, that the channels of departure and return in the syringe are single tubes, but in the body are tubes with innumerable branches, of which the extremities, of capillary size, open or inosculate into one another. It is further to be noticed, with respect to the circulation in warm-blooded animals, that there are really two distinct hearts, although so connected as to appear one : the first, on the left side, serves the purposes of the general circulation ; the other, on the right side, receives all the dark-coloured and impure blood returning from the general circulation, and sends it through the shorter circulation of the lungs, where it is depurated or purified, and acquires a bright red colour from the oxygen of the air breathed, before it again enters the left side of the heart for general circulation through the body.

The *pulse* is merely the sudden gush of blood driven into the great trunk of the arterial tree, the aorta, by the sudden contraction of the heart, causing an undulation over the whole system. It takes place visibly in all arteries above a certain size, and it can be felt in those which are superficially covered with skin or which lie over bone, as in the radial artery at the wrist.

1089. Among the facts in nature offered to man's observation, there is perhaps nothing more marvellous than that, out of the same red opaque fluid, *the blood*, which, if drawn from a vein and allowed to stand at rest, is quickly turned into a soft coagulum and a straw-coloured liquid (serum), the living powers in the body should find and separate from the mass the materials of which all other solids and liquids in and about the body are formed.* How strange, that these powers can produce from this liquid the pure watery tear which constantly keeps the eyeballs moist and clean—the colourless saliva, the milk, and the deadly poison of the cobra and rattlesnake, as well as the curved teeth or fangs through which this poison is ejected! These liquids and solids are not only formed by and from the blood, but each is deposited in its due place and proper proportion for its intended future use. In reference to human beings, it may be observed, that all the varied secretions of the body—the milk, bile, and gastric juice, as well as the materials of solid flesh, skin, hair, nails, the hard bones, and the enamel of the teeth, are derived from this wonderful fluid. It is stranger still that, after finding the fit materials, these living powers are able therewith to construct such curious and complex organs as the eye, the ear, the brain, and the heart. Then we see in all the inferior races of animals the like phenomena going on. Out of the blood of the creatures, are formed the teeth and claws of the tiger, the proboscis and tusks of the elephant, the shell of the tortoise, the fur of the beaver, and the feathers of the peacock with their radiant colours and symmetrical arrangement. Neither physics nor chemistry can reasonably furnish an explanation of these phenomena. They are referable only to the exercise of powers of a special kind acting within the living body and entirely independent of the will or consciousness of the living animal.

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* The blood in all warm-blooded animals owes its red colour to the presence of a number of minute cells or bladders containing red colouring matter. These are mechanically diffused, and float in the liquid portion or serum. They are of larger size in man than in most other animals. They have an average diameter of the 3500th of an inch. A drop of blood owes its intense colour to the aggregation of these small bodies. The number contained in the blood of the human adult cannot be less than sixty-one billions. At a late scientific meeting at South Kensington (1876), Dr. J. B. Sanderson described the method of microscopical measurement, and stated that the normal standard is four millions of red corpuscles in a cubic millimetre, *i.e.*, a cube of the twenty-fifth part of an inch.

1090. In order to complete this series of wonders it may be noticed that each species of animal, in search of the food which is to make its blood, errs not as to the kind of food which will yield the ingredients required. Thus the elephant lives upon vegetable substances. These not only supply what is necessary for the growth and nutrition of the animal, but also those mineral matters which build up its defensive ivory tusks. Ivory, like bone, consists of two-thirds mineral matter—the phosphate and carbonate of lime. These mineral ingredients exist only in small proportion in the vegetable food of the animal, but they are extracted, eliminated, and deposited as ivory in the enormous tusks of the male elephant. Sir Samuel Baker describes a pair of tusks of a large African elephant as weighing 150 pounds (the weight of a full-grown man). These would contain at least 100 pounds of mineral calcareous matter transferred from the vegetable food to the blood of the animal, and by it fashioned under the vital force into that most beautiful substance, ivory. The large amount of food required to supply the mineral matter for building up the tusks of an elephant may well excite wonder, but that wonder is greatly increased when it is considered that there is a power of selection and transposition of these mineral substances which is incessantly going on in the living animal. We witness in other animals the same wonderful series of transformations. The blood of the cow is converted into a white, oily, saccharine liquid, *milk*, wholly different from blood in its physical and chemical properties. In the young animal, the calf, this white liquid serves as nutriment, producing blood, flesh, bone, fat, and all the other constituents of the body.

1091. It is the more necessary to insist upon these characters of living bodies, because some modern physicists and chemists of repute profess to see in life nothing but physical and chemical forces. An eminent philosopher has compared a living animal to a voltaic battery. So long as the battery is supplied with zinc and acids, a current of force is set up by which marvellous results are obtained. Withdraw these materials and all action ceases. In the living animal the food represents, according to this hypothesis, the zinc and acid, and the brain and nervous system the medium by and through which the so-called "vital" energy is manifested. Remove the food and you have what is called death.

A chemist of repute has treated the idea of the existence of any vital force, independently of chemistry and physics, as an obsolete dogma no longer received in modern science. He rests this view upon the fact that some substances, such as certain acids and principles hitherto called organic, have been artificially produced by chemical processes and quite irrespective of any so-called vital force; and from a few instances of this kind, he draws the hasty conclusion that in time all the constituents of the living body will be obtained by chemical processes in the laboratory.

It has always appeared to the writer that there is a great fallacy in this mode of reasoning. With regard to the illustration from the Voltaic battery, the points in which the comparison utterly fails have been studiously ignored. The *living* machine can not only go on working and at the same time repairing itself when needed, but it can multiply itself and produce an endless succession of similar machines invested with similar powers to its own. So, again, assuming that a chemist can produce artificially a liquid like albumen, a solid like starch, or a red colouring matter resembling blood, he is still very far from having solved the problem by which living is separated from dead matter. The vital force in the vegetable and animal not only produces these substances, with certain chemical properties, but invariably arranges them in a certain form.

They are organized as well as organic. The albumen presents itself in the living body in the form of feathers, hair, nail, and tortoise-shell. No physical or chemical energy, however applied, has yet succeeded in converting albumen into a feather, or starch into a granule of complex shape and structure, or in creating a single blood-cell out of any kind of red colouring matter.

It has been well observed that the limits of stature and growth in animals and vegetables, the persistence of form, and the reparative power manifested by the spontaneous restoration of injured or damaged parts, are forces or energies wholly different from those physical and chemical forces which govern inorganic matter. Why does the animal or vegetable grow, and why, if it once grows, does it ever cease to grow? Inorganic bodies are subject to physical and chemical changes, but we see in them nothing analogous to growth, maturity, and decay—stages which are inseparably connected with and invariably follow each other in bodies endowed with life. Other questions naturally arise out of these, which show in the strongest possible light, the existence of forces or energies, whether called " vital " or by any other name, wholly different from those of physics and chemistry. Why, in the process of growth, do bones remain bones, arteries, arteries, and nerves, nerves ; and why is growth invariably controlled in its degree by the use or purpose to which the parts are put? These questions admit of no answer, so far as the laws of physics and chemistry are concerned. They are referable only to another force or energy wholly different in kind.

Force of the heart and motion of the blood in the Arteries.

1092. The contractions of the heart inject the blood into the arteries with a force maintaining such a tension in them, that, according to the interesting experiments of Dr. Hales, recorded in his *Statical Essays*, if any artery of a large animal like a horse be made to communicate with an upright tube, the blood will ascend in the tube to the height of about ten feet above the level of the heart, and will there continue, rising and falling a few inches with each pulsation of the heart. Now a column of *ten* feet, as explained in Art. 418, indicates a pressure of about *four and a half* pounds on a square inch of surface : this, therefore, is the force of the heart urging the blood along the arteries and through the capillaries into the veins. Recent experiments by physiologists have led to nearly similar results. The static force with which the blood is impelled into the human aorta, is calculated to be equal to four pounds four ounces, and that in the radial artery at the human wrist at only four drachms. The tension of the veins is much less, because of the resistance offered by the capillaries, and because the blood readily escapes from the veins into the heart. It is in the capillaries that the chief resistance is offered to the progress of the blood, for in them there is greatly increased friction by reason of the increase of surface with which it is brought in contact, and as the stream is widened its velocity is diminished. Hales found that in a tube communicating with a vein, the blood stood only a few inches higher than the level of the heart. In small animals he ascertained the tension of artery and vein to be less than in large ones; and the ratios deduced for the human body, under ordinary circumstances, were eight feet column, or nearly four pounds per inch, for the arteries; and half a foot column, or a quarter of a pound per inch, for the veins. The least pressure on the top of either column will lift up the other; so, when the body is erect, the least pressure on the column of arterial blood may lift up the venous blood, and, were it not for the valves, the least pressure on the venous might lift up the arterial column.

Passage of the blood through the Capillaries.

1093. We have seen above that the heart keeps up a tension or pressure in the arteries of about four pounds on the square inch of their surface; and with this force, therefore, is propelling the blood into the capillaries. If these last were passive tubes, constantly open, such force would be sufficient to press the blood through them with a certain uniform velocity: but they are vessels of great and varying activity: it is among them that the nutrition and repair of the different textures of the body take place, and that all the secretions from the blood are performed, as of *bile*, *gastric juice* or *saliva;* and to perform such varied and often fluctuating offices, they require to be able to control, in all ways, the motion of the blood passing through them. The capillaries of the cheek, under the influence of shame, dilate instantly, or lose their ordinary contractile power, and admit more blood, producing what is called a *blush;*—while under the influence of anger or fear, they suddenly contract and empty themselves, and the countenance becomes pallid —tears or saliva, under certain circumstances, gush in a moment, and in a moment again are arrested. The action of cylindrical vessels, capable of causing these phenomena, depends on a contraction and dilatation of their coats under a special system of nerves, called vaso-motor.

A muscular capillary tube, strong enough to shut itself against the arterial current from the heart, is strong enough also to propel the blood to the heart again through the veins, even if the resistance on the side of the veins were as great as the force on the side of the arteries. For if we suppose the first circular fibre of the minute tube to close itself completely, it would, of course, be exerting the same repellant force on both sides, or as regarded both the artery and vein. If, then, the series of such fibres forming the tube were to contract in succession towards the vein, as the fibres of the intestinal canal contract in propelling the contents of that canal, it is evident that all the blood in the capillary would thereby be pressed into the vein towards the heart. If after this the capillary again relaxed on the side of the artery, so as to admit more blood, and again contracted towards the vein as before, it would produce a forward motion of the blood, first towards the vein, and then in it, independently of the heart, and might carry on a slow circulation if there were no heart.

Passage of the blood through the Veins.

1094. The veins have much thinner coats than the arteries, and, if taken altogether, have much greater capacity: for besides being larger than the corresponding arteries, they exist, in many situations, as double sets, an exterior and an interior: they have also very frequent inosculations or communications with each other throughout their whole course, and there are in many places folds of the internal coats which act as valves, allowing a current in only one direction, namely, towards the heart. These valves, like locks in a canal, divide the column of blood, and lessen the pressure on any one part. In some persons, as they advance in age, owing to a thinning and weakening of the venous coats, the pressure of the blood downwards, as the result of gravitation, so distends the vein as to prevent this mechanical action of the valves, and the disease called *varix* (from *varus*, uneven or crooked), is thereby produced. The vein is unnaturally enlarged, and becomes tortuous in its course. For obvious reasons varicose veins are chiefly seen in the legs, especially of aged persons.

There are no valves in the veins of those organs where their presence would interfere with the free passage of the blood. Thus the veins of the lungs have no valves. They bring to the left side of the heart the blood which has undergone aëration in the lungs.

It is estimated that the capacity of the veins is about three times as great as that of the arteries, and that the velocity of the blood's motion in them is about one-third less than in the arteries. The rate at which the blood moves in the veins gradually increases the nearer it approaches the heart—the sectional area of the venous trunks becoming gradually less. (Kirkes.)

The simple weight of the column of blood in any descending artery is just sufficient to raise the blood through open capillaries to an equal height in the corresponding vein, according to the hydrostatical law, that fluids attain the same level in all communicating vessels; and therefore, as the arch of the aorta rises considerably above the heart, the gravitating pressure of the descending arterial column of blood would be sufficient to lift that in the veins, not only up to the heart, but considerably beyond it. In addition to this influence of gravity on the venous current, the blood is pressed into the arteries, and from them, therefore, towards the veins, with a force from the heart itself, as stated above, of about four pounds to the square inch, or, in other words, as if there were a column of blood eight feet higher than the heart urging the current. It might be expected from the law of equal diffusion of pressure in fluids, that these causes would soon produce a tension in the veins as great as in the arteries: and this does not happen, only because the blood has a ready escape from the veins through the right auricle and ventricle of the heart. Under ordinary circumstances, there can be no greater tension in the veins than what is sufficient to lift the blood to the level of the heart and to overcome the friction.

1095. These facts, then, and others that might be mentioned, prove incontestably that the blood is pressed into the veins from the arteries and capillaries, with a force sufficient to lift it, not only to the heart again, but many feet farther, *viz.*, about as far as it would ascend in a tube rising from the tense arteries themselves. A difficulty appears to have arisen in admitting this explanation from the great disparity observed between the tension in the arteries and in the veins; while it was not considered that this disparity was owing to there being a free passage or outlet from the veins through the heart.

Physiological experiments confirm the view that the contractions of the heart alone supply a sufficient force for the circulation of the blood :—1. When the heart is removed the circulation stops abruptly and completely. 2. When the main artery of a part is tied there is no circulation in the vessels beyond it. 3. When circulation is carried on in a limb only by the main artery and vein, all other parts being secured, the current through the vein is completely arrested by the compression of the artery. (Kirkes.)

The office of the arteries in the circulation is thus described by this physiologist :—1, the conveyance and distribution of blood to the several parts ; 2, the equalization of the current and the conversion of the pulsatile jetting movement given to the blood by the left ventricle into the uniform flow ; and, 3, the regulation of the supply of blood to each part. This threefold office is accomplished by the combination of the elastic and muscular coats of the arteries.

A knowledge of the facts detailed under the three heads of *arteries*, *capillaries*, and *veins*, prepares us for the discussion of the following subjects.

The force of the Heart.

1096. The arterial tension of four pounds to the square inch, marked by its supporting in a tube connected with the arteries, a column of blood eight feet high (see Art. 1092), is produced by the action of the heart ; but as the heart, while injecting the blood, has moreover to overcome the resistance both of the quantity injected and of the mass in the great artery, first moved by the injection, as also the resisting *elasticity* of the vessel which yields to a momentary increase of pressure, the heart must act with a force exceeding four pounds on the inch. As the left ventricle of the human heart, when distended, has about ten square inches of internal surface, the whole force exerted by it is a matter of simple calculation.

The force with which the left ventricle contracts, is twice as great as that exerted by the contraction of the right. Valentin, a modern physiologist, estimates this force at $\frac{1}{80}$th the weight of the whole body, while that of the right ventricle is equal to $\frac{1}{100}$th. This would give in a man weighing 150 pounds a force for the left ventricle of about three pounds and a half. The difference in the amount of force exerted by the two ventricles, arises from the walls or muscular substance of the left being twice as thick as those of the right. The left ventricle has a greater resistance to overcome. While it has to propel the blood through every part of the body, the right ventricle is required only to force it through the lungs.

The capacity of the two ventricles is considered to be nearly equal, and each contains on an average three ounces of blood, the whole of which is thrown into their respective arteries at each contraction. According to Dr. Kirkes, the heart of a healthy adult man in the middle period of life, acts from seventy to seventy-five times in a minute. Assuming seventy contractions as a standard, 210 ounces, or about 13 pounds of blood, would thus pass through the heart in a minute. If the quantity of blood in an adult is taken at 30 pounds, the whole would be circulated and distributed through the body by the contractions of the heart in two minutes and one-third. Valentin has calculated that the whole of the blood may pass through the heart in 62 seconds. This will convey some idea of the astonishing rapidity with which substances are absorbed by the blood and conveyed to all parts of the body.

The pulsations of the heart gradually diminish from the commencement to the end of life. Just after birth they are 140 in a minute; during the third year 100; at the seventh year 90; in the middle period of life 75 to 70; and in old age 65 to 60.

Some physiologists have expressed surprise that the force of the heart should be so great as it is, remarking that much less would have sufficed to propel the blood to the most distant capillaries; but they did not reflect that the heart, besides carrying on the general circulation, has to force blood into those parts of the flesh which, in the various positions of sitting, lying, or standing, are for the time compressed by the weight of the body above; for if it were not strong enough for this purpose, either the compressed parts, deprived of their nourishment, would quickly die, or the person, obliged to be every moment changing his position, could obtain no lengthened repose. A pressure equal to that of one and a half or two inches of mercury is considered to be sufficient to propel the blood through the vessels of the lungs.

The Pulse.

1097. The opinion which the ancients held that the arteries contained *vital spirits* or *air*, and not blood, rendered the pulse to them a very mysterious phenomenon; and many curious hypotheses were framed to explain it. We now know that each gush of blood thrown into the aorta from the great left chamber of the heart, causes an undulation, perceptible to the touch, to spread from the heart to the most distant extremities.

By an ingenious application of mechanics, an instrument called the *sphygmograph* has been invented and applied to the determination of the form, force, and frequency of the pulse as felt at the wrist. The instrument is so secured over the radial artery that at each pulse-beat a lever is raised, and this communicates the impulse to another lever armed with a pen-point, which has a vertical movement, and records the result in an irregular line. A strip of paper is moved by machinery steadily across the pen-point, and thus receives the undulating mark produced by it. The height of the elevations indicates the *strength* of the pulse, and the number of them over a given space, its *frequency*. Valvular and other diseases of the heart are thus indicated by the sphygmographic tracings on the paper.

The annexed figures illustrate the state of the pulse as taken under different conditions; 1 represents the pulse of a healthy man, aged twenty-three, the pulse being 72; 2 represents the pulse of the same man after he had taken a small dose of nitrite of amyle, a narcotic; 3. Pulse at the commencement of typhoid fever; 4. The pulse on the thirteenth day of a severe case of typhoid fever. These are taken from observations made by Dr. Galabin.

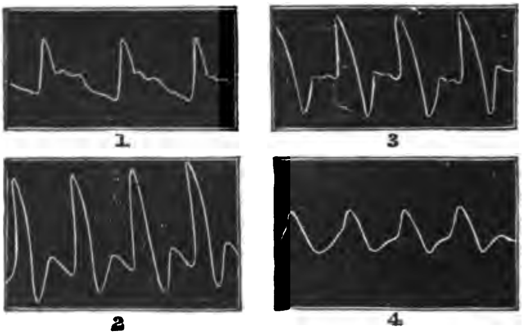

Fig. 326.

It is a remark respecting the pulse, worthy of full consideration, that if the purpose of the heart and arteries were merely the propulsion and conveyance of the blood, their structure and action would form signal deviations from the ascertained rules of fitness in mechanics. In machines of human contrivance, it is one of the most important maxims "to avoid shocks, or jerking motions;" and in former parts of this work, we have described fly-wheels, air-vessels, and springs, as means of accomplishing this object, and thereby of preventing the wearing and straining of parts which else might happen. In the human body, also, we have had to describe the admirable elasticity of the spine, of the arch of the foot, and of the cartilages of joints, as contrivances answering the same ends. The heart alone is the rugged anomaly which, from before birth unto the dying moment, throbs unceasingly, and sends the bounding pulse of life to every part; and which, moreover, instead of being secured and tied down to its place, is attached at the extremity of the aorta, like a weight at the end of an elastic branch of a tree, and every time that it fills the aorta, is thrown with violence, by the consequent sudden tendency of that vessel to become straighter, against the ribs on the left side, in the place where the hand applied, feels it so distinctly beating. This impulse is most evident in the space between the fifth and sixth ribs, between one and two inches to the left of the chest bone.

1098. The action of the heart is the first indication of life (*punctum saliens*), its cessation is the true point of death (*ultimum moriens*). In death from asphyxia (suffocation) the heart continues to pulsate for three or four minutes after respiration has ceased, and while the animal is quite insensible. This has been called apparent death. The state of hybernation in animals is somewhat similar. There is not an actual stoppage of the action of the heart, for this would be inconsistent with the maintenance of any life in the body, but the heart pulsates more feebly and at much longer intervals. It has been found that in the marmot, or mountain rat, when the animal was in an active state, the pulsations of the heart were 90, while in the torpid or hybernating state, they were reduced to 8 or 10 in a minute.

It is remarkable that there are some vegetable poisons which act specially on the heart, and reduce its contractions even to the suppression of them altogether. This is the effect of the ordeal bean of the West Coast of Africa (*Calabar bean*). It is there used as a test for witchcraft. An eminent physiologist took a small quantity in two doses, in order to test its action. In twenty minutes he became faint and utterly powerless, and his pulse was reduced to thirteen in a minute. To the bystanders it appeared as if it would stop altogether, when, fortunately, reaction took place and he recovered.

1099. Although the action of the heart is independent of the will, in some rare cases a person has had the power of voluntarily reducing its pulsations, and of passing spontaneously into a state of apparent death. Dr. Cheyne, an eminent physician of the last century, describes the case of a Colonel Townshend, who in his presence so suspended the pulsations of his heart, that no pulse could be felt at the wrist, and the Colonel remained in a lifeless state for half an hour, when he slowly recovered. There is no doubt that his heart continued to act during this time, but at long intervals, as in the hybernating animals, although no pulse could be felt. The stethoscope, which, when applied to the chest, allows the feeblest sounds of the heart to be heard, had not then been invented. Although the Colonel perfectly recovered, he died nine hours after the performance of the voluntary experiment above-mentioned, and nothing could be found in his body either to account for his death or for the possession of this singular power.

1100. The heart has been elsewhere described as the pump of the blood (Art. 1088), and its action in the body has been compared to the pump-barrel and piston worked by steam, which distributes water through the mains and pipes of a great city. While the mechanical effects are similar, there are differences which require notice. The action of the heart is unceasing so long as life continues. In an adult whose pulse numbers only 60 in a minute, the heart makes no fewer than 86,400 pulsations in the twenty-four hours. Its action has been maintained at this rate for eighty, ninety, and even one hundred years. The heart of an infant will go into the cavities of the heart of an adult; hence the whole substance of the organ must have been removed and replaced in the adult, but still retaining its form, position, and action. Here we come upon the vast differences which exist between physical and animal mechanics. The steam-pump manifests neither growth nor change, but rapidly wears out from the friction of its parts, and is not renovated except by the hand of man; the blood-pump passes spontaneously, like all living matter, through stages of growth, maturity, and decline, and while doing an amount of work which would soon wear out any ordinary machine or engine, is able when so working to repair its own daily waste for a hundred years, without in any way interfering with its mechanical functions. These differences should be considered when we are called upon to admit the theory of a modern school of philosophers who deny the existence of "living" powers, and who can see nothing in a living body but that which is explicable by physics and chemistry.

1101. One use of the pulsation of the heart probably is seen in the *agitation* and kind of *churning* which the blood suffers in passing through it, to keep in complete mixture, all the heterogeneous parts of this fluid, which so readily separate from each other when left to repose; but this cannot be the only use, for that one object might have been more simply attained; and we may conclude that the phenomenon has relation to some important law of life yet veiled from us. The cause commonly assigned for the heart's contraction is a peculiar stimulus of the blood; but the fact that its movements continue with the same order and regularity after its removal from the body, and that when these cease they may be re-excited by any ordinary mechanical stimulus, proves that the cause of these movements must be within the heart itself. We also observe that during life it beats with extraordinary regularity, whether the state of the circulation allow it to empty itself at each beat or not.

RESPIRATION OR BREATHING.

The chest is a cavity which alternately expands and contracts like a pair of bellows, thereby taking in and again expelling a certain volume of atmospheric air. This air comes nearly into contact with every particle of the circulating blood as that passes at every revolution through the spongy lobes of the lungs occupying the chest. These lobes consist chiefly of delicate air-cells and minute capillaries, so thin that air can act through their substance. Great changes are produced in the blood by the manner of contact described, and it is thereby rendered fit to support life.

1102. The life of that complex structure, the animal body, depends on the continuous supply of air for the purposes of respiration. Unless that which has been respired is removed and a fresh quantity supplied, the vital functions are speedily arrested.

Experiments on dogs made by a committee of the Medico-chirurgical Society have shown that this animal may be deprived of air for a period of three minutes and fifty seconds, and afterwards recover when air is admitted into the lungs; but if the privation of air is carried to a period of four minutes and ten seconds, the animal dies. The turning-point between life and death is thus limited to twenty seconds! It is not likely that under these circumstances a man would survive longer than a dog. Thus the life of a man would be destroyed in from four to five minutes after the power of breathing had been completely arrested.

The mechanical nature of air, as to its lightness and elasticity, and the fact of its forming an aërial ocean around the earth of about fifty miles high, are now well understood, and have been fully explained under *Pneumatics;* but the precise nature of its life-sustaining action has yet to be elucidated by additional researches of chemists and physiologists. We know that the ingredient called *oxygen,* constituting a fifth part of the atmosphere by volume, and rather more by weight, is the most essential part. It is the great supporter of respiration, and is largely consumed during this process (see Art. 764): hence air deprived of oxygen by breathing, or by ordinary chemical changes, is wholly unfitted to support animal life or combustion. If a lighted wax taper is introduced into a jar of air, in which iron filings have been sprinkled with a little water, it will be found, after some hours, that the residuary gas, which is nitrogen, will extinguish it; and any small animal introduced into the gas will be instantly rendered lifeless. 1. If we breathe by a wide tube into a bell-glass filled with water, and inverted on a water-bath, so that the water may be entirely displaced by the expired air as it issues from the lungs—we shall find, on introducing a lighted wax taper, that it will be instantly extinguished. 2. A lighted taper introduced into a bell-glass of air, placed over a water-bath (the bell-glass being closed at the top by a brass-plate or stopper), will be extinguished in a few minutes, owing to the rapid consumption of oxygen and the absence of any fresh supply. On removing the extinguished taper quickly and introducing another, lighted, this will also be extinguished; and any small animal placed in either of these mixtures, thus deprived of a large portion of their oxygen, would soon perish. It must not be supposed, however, that *all* the oxygen is removed from air, either by breathing or by ordinary combustion. That there is still some portion left in the glass vessels, may be proved by introducing into them a ladle containing a small piece of phosphorus ignited. This will continue to burn at the expense of the residuary oxygen not removed by the lungs in breathing, or by the wax-taper in combustion.* Air, therefore, which is deoxidized, or which does not contain a certain amount of free oxygen, cannot support life. Respiration and combustion operate in a similar manner, *i. e.,* they vitiate the air by removing oxygen and supplying its place with carbonic acid. As a general rule, an animal cannot live in air in which a wax-taper will not burn, and a taper will not burn in an atmosphere in which there is too small an amount of oxygen to maintain respiration.

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* Some invertebrate animals, such as slugs, have the power of removing all the oxygen, and replacing it by carbonic acid in an equal volume. They, therefore, act as eudiometers. A human being will die in air containing ten per cent. of carbonic acid as the result of breathing.

1103. It has been elsewhere stated that if our atmosphere had consisted of oxygen alone, combustion once set up would not have ceased until all combustible substances had been consumed, and the whole face of the earth changed. So in regard to animal life, although oxygen is absolutely necessary to respiration—when this gas is in a pure state, *i.e.*, unmixed with nitrogen—it operates as a powerful excitant to the nervous system; and a small animal confined in an atmosphere of pure oxygen will die in a few hours, apparently from the excessive stimulus produced by the gas. Mr. Broughton found that rabbits died in six, ten, or twelve hours when confined in oxygen. The dilution of the oxygen of the atmosphere with four times its volume of nitrogen is therefore absolutely necessary to animal life. It is worthy of notice, however, in reference to this noxious action of pure oxygen, that an animal will live three times as long in this gas as when it is confined in an equal volume of common air. The reason for the difference is, that the quantity of oxygen in air available for respiration, is not only four-fifths less, but that which has been consumed by the animal is replaced by an equal bulk of carbonic acid, which is itself a noxious gas.

1104. A full-grown adult receives into his lungs and vitiates on an average 324 cubic inches of air in a minute.* As there are 277 cubic inches in a gallon, this amounts to nearly a gallon and a half of air, or, in other words, a cubic foot of air is rendered unfit for breathing in less than six minutes. An ordinary candle with a full burning wick consumes the same amount of air as an adult. The miners of Cornwall, working at a depth of from 900 to 1200 feet below the surface, come up pale and exhausted after a few hours' work. There are no means of renewing the air by ventilation at these great depths, and it is rapidly vitiated, not only by breathing, but by the necessary combustion of candles. While pure air on the surface contains only one cubic inch of carbonic acid in 2500 cubic inches, air obtained from a deep Cornish mine was found to contain from one to two per cent. of this noxious gas. In this we have an explanation of the fact that a man is rapidly suffocated when the supply of fresh air is cut off. The enterprising Mr. Spalding, who introduced the use of the diving-bell, descended for the last time with a companion on the coast of Ireland. Owing to the signal cord becoming entangled round the great rope supporting the bell, which had turned in descending, he could not make known above their want of air, and both were found dead when the bell was drawn up soon after, although the water had not touched them.

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* This is here stated as an average; but, according to some physiologists, the quantity of air taken into the lungs at each inspiration, amounts to thirty cubic inches, and eighteen respirations are performed in a minute, hence this would give (30 × 18) 540 cubic inches in a minute, *i.e.*, nearly two gallons. The carbonic acid present in the expired air, varies from 3 to 10 per cent, while the inspired air contains of carbonic acid, only one cubic inch in 2500 or $\frac{1}{2500}$th part.

Similar accidents have occurred to divers under the use of the water-tight diving dress, now substituted for the ancient diving bell, and they throw a curious light upon the rapidity with which human life is extinguished, when the power of breathing fresh air is cut off. A healthy diver was accidentally submerged at Spithead in July, 1842, at a depth of eighty feet for a minute and a half without the power of breathing. When drawn up he was faint but sensible, and recovered under treatment. In August, 1864, a diver descended at Falmouth to about the same depth. From the time of his making the signal to be drawn up *two minutes* only had elapsed before he was taken into the boat. He was then quite insensible, but he was able to place his hand across his mouth. He did not speak, but gave a convulsive struggle and died soon afterwards. It was found, as in the previous case, that the pipe for supplying air had burst, and that the valve for the outlet of expired air had become fixed. The difference of time between recovery and death in these two cases was only *half a minute.*

1105. So that there is a proper supply of air, a man may breathe and carry on his operations at great depths in the sea for a considerable time. This is well known from the experience of divers in recovering salvage from wrecks. It is stated that the greatest depth to which any diver can safely descend with existing appliances, is about 160 feet. For this purpose, however, he would require to be weighted with at least one hundredweight of lead on his back and breast, in addition to a quarter of a hundredweight attached to the soles of his shoes. As the additional pressure on his body, at such a depth, will amount to many tons, it is wonderful that the chest can overcome such a pressure and allow a man to breathe compressed air and remain at work for a period of thirty or forty minutes. In one experimental trial an experienced diver is said to have remained for an hour and a quarter at a depth of thirty fathoms, but he died nine hours after he was drawn up, apparently from congestion of the lungs.

We know generally of the life-supporting action of air, that it consists in some change produced by oxygen in the blood, during which some substances are given to it, and others unfitted to support life are taken away ; and we know that the function of respiration has merely to bring air and blood together in the cavity of the chest, in order that this change may be effected. This action of the chest takes place at the rate of from fourteen to eighteen times in a minute, so that in a normal state for every act of breathing, there are from four to five pulsations of the heart. The quantity of air taken in at each inspiration depends on the capacity of the chest ; it varies from eighteen to twenty cubic inches. After a momentary contact with the dark blood in the cells of the lungs it is expired. The air thrown out of the lungs has not only lost much of its oxygen, but has acquired a large proportion of carbonic acid, so that it will no longer support respiration or combustion. An animal is suffocated in it, and the flame of a candle is immediately extinguished when plunged into air expired from the lungs.

The air-cells or ultimate divisions of the air-tubes are, in their natural state, always filled with air. In the adult human being they vary from $\frac{1}{200}$th to $\frac{1}{70}$th of an inch in diameter. These dimensions go on increasing from birth to old age. The capillary network of the pulmonary vessels is spread beneath the thin transparent mucous membrane which lines the air cells. The capillaries which contain the blood are very fine, the smallest measuring in injected specimens the $\frac{1}{2540}$th to $\frac{1}{5000}$th of an inch in diameter. The meshes in injected specimens are scarcely wider than the vessels themselves. (Sharpey.) The coats of these capillaries are also exceedingly thin, and thus more readily allow of the permeation of gases in breathing, and the free exhalation and absorption, of which the pulmonary cells are the seat.

The blood, while in the chest, is moving along a part of its course, in vessels of extreme minuteness and thinness, distributed over the air cells, and the air at each inspiration penetrates the thin membrane, so that every globule of blood passes within its influence. The blood, which, after having served the purposes of the body, arrives at this part of its course dark and impure, immediately after its exposure to the air, enters the left chamber of the heart, of a bright scarlet colour, and thence departs to carry new life to the general system.

1106. From the minuteness and number of these cells, the whole area which they present for the aëration of the blood is very large. Some authorities have considered it to be equal to the area of the body of a full-grown adult, *i.e.*, fifteen square feet. Others, like Keil and Hales, assign a much larger surface. They have calculated that the inner surface of the air tubes and pulmonary cells is equivalent to 21,000 square inches, or 145 square feet. The effect produced on the large surface of blood spread in a thin sheet over this immense area is instantaneous. Expiration, therefore, immediately follows inspiration. Both acts are completed in from three to four seconds. Owing to this great extent of surface, when the air breathed is strongly impregnated with poisonous gases or vapours, the poison at once enters into the blood, and causes immediate insensibility and death. But the unaërated blood itself may operate as a poison. When, in asphyxia or suffocation, the breathing is suspended, the heart circulates for a short time the unchanged blood. This penetrates to all parts of the body, and as it is unfitted to sustain nerve-force in the brain, spinal marrow, and other organs, death is the result. It is only the aërated or bright scarlet blood which is fitted to sustain life or vital energy. The poison of venomous serpents, such as the *cobra di capello*, darkens the blood, producing insensibility and apparent death, a condition resembling asphyxia or suffocation. If, while in this state, artificial respiration is performed the animal recovers, and the maintenance of this supply of air to the lungs, has been found one of the best methods of treatment for persons who have been bitten by venomous serpents. The comb and wattles of a cock owe their bright red colour to the blood circulating in the capillaries. Sir J. Fayrer noticed in a cock bitten by a cobra, that these parts lost their florid red colour, and became dark and livid. When air was thrown into the lungs the animal revived, and the florid red colour of the comb and wattles returned. This was a visible demonstration of what takes place in the blood distributed over the air cells of the lungs, when air is supplied or cut off.

1107. The force of a healthy chest's action in the act of blowing, is equal to about *one pound* on each inch of its surface; that is to say, the chest can condense its contained air with that force, and can therefore blow through a tube the mouth of which is two feet under the surface of water. In the opposite action of sucking or drawing in air, the power is nearly the same. In both actions, however, it is possible to use the cavity of the mouth separately from that of the chest; and the mouth being smaller, with stronger muscles about it in proportion to its size, it can act more strongly. Some men can suck with the mouth so as to make nearly a perfect vacuum, or to lift water nearly thirty feet, others cannot raise a column in a narrow glass tube higher than six feet. An expert operator with the blowpipe can keep up an uninterrupted blast by shutting the mouth behind, while he gently inhales, and replenishes the air as it is required in the intervals.

1108. When a man strains to lift weights, or to make any powerful effort, the air is shut up for the moment in the chest, that there may then be steadiness and firmness of the general person. At such a time, by the compression and condensation of air around the heart and larger blood-vessels, the blood is determined violently outwards from the chest, and often rises to the head, with a force that produces giddiness, or even apoplexy,—and the eye will sometimes become suddenly bloodshot, from a small vessel giving way. The force of this pressure outwards is measured, as already stated, by a column of about two feet of blood; and this is therefore the measure of the additional arterial tension in the body generally.

The capacity of the lungs has been variously estimated. After a forced expiration, Goodwyn calculated that these organs still contained 109 cubic inches; while, after an ordinary expiration, 170 cubic inches are supposed to be retained. Hutchinson found that, on an average, men between five and six feet in height, after a complete inspiration, could expel from the chest by a forced expiration 225 cubic inches of air at a temperature of 60°. If to this we add the average residual quantity found by Goodwyn, namely, 109 cubic inches, it follows that the average total capacity of the lungs in an adult male is 335 cubic inches. The proportionate weight of the lungs to the body is, in the adult male, 1—37, and in the adult female, 1—43.

1109. The aspiratory force of the lungs during inspiration is very great, and, unless controlled, it may be a cause of accidental suffocation. Substances placed in the mouth may be thus readily drawn into the air-tubes and lungs, and so obstruct breathing. By plunging the heads of animals into mercury, some of the fluid metal, in the shape of minute globules, has been drawn into the lungs by the efforts made to breathe. This force has been measured, and it is found, in small animals, to be equal to raising a column of mercury four inches in height. This is equivalent to about one-seventh of an atmosphere. In recently drowned persons, it is not unusual to find portions of sand, weeds, or other floating substances in the air-tubes or air-cells of the lungs. They have been carried there as the result of this aspiratory force in the last struggles for life. Water is also carried thereby into the substance of the lungs, rendering them sodden and wholly unfit to receive air. When the lungs in drowning are thus penetrated by water, there can be no hope of recovery.

Children and drunken persons, placed with their mouths in ashes, feathers, or similar substances, are sometimes suffocated, owing to their helpless condition, and portions of the ashes or feathers are found in the air-passages. The making of a sudden and deep inspiration while food or any other foreign substances are in the mouth, is for this reason always attended with great danger.

The function of *digestion* or assimilation of food for the support of the body, and the continuous restoration of the waste of tissue, has a more direct relation to Physiology than to Physics. It is, therefore, unnecessary to introduce a notice of it in this place.

1110. *The Hydrostatic bed.*—The hydrostatic or floating bed for invalids consists essentially of a water-tight trough of the dimensions of a common sofa. Water is poured into the trough to the depth of about six inches, and a sheet of waterproof cloth is then laid over the surface, and so secured to the edges as to float freely on the water. A thin mattress is placed over the cloth, and over this again, a folded blanket. In order to prevent the condensation of the insensible perspiration, a thin sheet of caoutchouc cloth is placed above the mattress, so as to prevent the vapour from coming into contact with the lower sheet. It may thus be prepared as an ordinary bed, with this difference, that the pressure on the body of a person lying on it is equal in all parts. Unlike any other bed, it allows of no local pressure, and does not interfere with the free circulation of blood in the capillary vessels. A patient, when capable of only feeble efforts, is able to change his position, almost like a person floating in a bath, and so to take a degree of exercise affording the kind of relief which persons in a constrained position obtain by occasional stretching, or which an invalid seeks by driving out in a soft-springed carriage. A person lying on the soft water-bed does not require to be frequently changing his position as on harder beds, and he may consequently rest so long in one position that the unmoved joints acquire a degree of stiffness. Such effect is altogether avoided by purposely changing the position from time to time.

With this bed, evidently, the fatal termination called sloughing, or bed sores, now very common in fevers and other diseases, need not occur at all. Not only can it prevent such a termination, but by alleviating the distress through the earlier stages, it may prevent many of the cases from ever reaching the degree of danger. This bed, used without the mattress, acts in some respects like a warm or a cold bath, without allowing the body to be touched by the water; and in India it might be used as a cool bed for persons sick or sound, during the heats which there prevent sleep and endanger health. There are numerous other professional adaptations and modifications of the principle of the bed, which will readily occur to practitioners sufficiently versed in the department of natural philosophy (hydrostatics) to which it belongs.

Experience has fully confirmed all that had been anticipated from the use of these beds. It is now so well known to the public and profession, that any further detailed description of it is unnecessary.

THE END.

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